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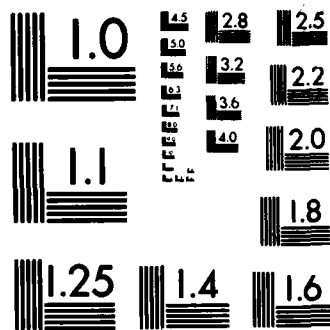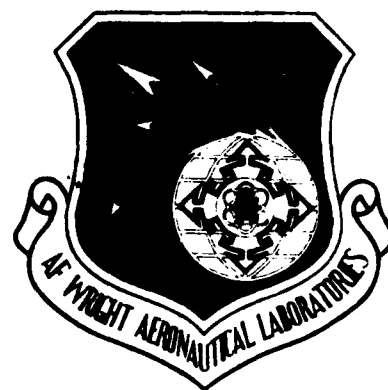
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SYMBOLOGY VERIFICATION STUDY

Carole Jean Kopala, Capt., USAF
John M. Reising, PhD
Crew Systems Development Branch
Flight Control Division
Flight Dynamics Laboratory

and

Gloria L. Calhoun
Emmett L. Herron
The Bunker Ramo Corporation
Electronic Systems Division
Westlake Village, California

January 1983

Final Report for Period 1 November 1978 - 30 May 1979

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JOHN M. REISING
Engineering Psychologist
Crew Systems Development Branch
Flight Control Division

TERRY J. EMERSON
Acting Chief
Crew Systems Development Branch
Flight Control Division

FOR THE COMMANDER

H. MAX DAVIS
Assistant Chief
Flight Control Division

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Multifunction control	Color coding
Aircraft displays	Threat displays
Shape coding	Human factors

20. ABSTRACT (Continue on reverse side If necessary and Identify by block number)

This study was performed to evaluate a proposed symbology set for real time combat situation displays in fighter aircraft. The primary objective was to compare pilot performance under two different coding conditions: a) shape coding only, and b) both color and shape coding. Color coding was found to significantly reduce overall average response time, with this effect becoming more pronounced with increasing symbol density. The second purpose

(Cont'd)

20. ABSTRACT (Cont'd)

of the study was to compare performance differences among the symbol types for each of the three states (friendly, unknown, or hostile). Data on this topic is evaluated and possible explanations for discrepancies are noted.

FOREWORD

This technical report is the result of a work effort performed by the Display Information Interface Group of the Crew Systems Development Branch (FIGR), Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. Robert Boundurant III was the group leader and Dr. John Reising was responsible for human factors. Mr. Emmett Herron of the Bunker Ramo Corporation provided pilot inputs to the work efforts, and Ms. Gloria Calhoun of the same company provided statistical and experimental design support. Software support was provided by Mr. Matthew Miller of Bunker Corporation; hardware support was provided by Mr. Al Meyer of Technology Incorporated. The objective of this effort was to evaluate a symbology set, in color and black and white, for a real-time combat situation display to be used in fighter aircraft cockpits.

The Bunker Ramo portion of the work effort was performed under USAF Contract Number F33615-78-C-3614. The contract was initiated under Task Number 240304, "Control-Display for Air Force Aircraft and Aerospace Vehicles," which is managed by the Crew Systems Development Branch (AFWAL/FIGR), Flight Control Division, Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories.

The final manuscript was typed by Wanda Kelley, The BDM Corporation, under contract F33615-81-C-3620.

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GLOSSARY OF TERMS

AAE - average absolute error - A summary statistic descriptive of the
error amplitude distribution of a sample of tracking performance.
Specifically, it is the mean of the amplitude distribution
replotted with all error amplitudes positive. It is an indicator
of variability.

AE - average error - A summary statistic descriptive of the error
amplitude distribution of a sample of tracking performance.
Specifically, it is a numerical index of the central tendency of the
amplitude distribution.

CCIP AUTO FLIGHT SEGMENT - CCIP - (Continuously Computed Impact Point)
AUTO is an A-7 bomb mode used to attack visually acquired targets
using dive or low altitude level delivery.

COLOR-CODING CONDITION - Experimental condition in which the symbols
were both shape- and color-coded to denote their states. Red was
used to denote hostile, yellow unknown, and green friendly.

COMPARING QUESTIONS - Questions in which the pilots were required to
compare specified symbols in two quadrants of the format.

COMPLEX QUESTIONS - Questions in which pilots were required to
recognize symbol orientation as well as symbol type and state.
Half of each type of question (Counting, Searching, Comparing) were
complex. Complex questions involved only aircraft symbols, not SAM
or AAA symbols.

COMPOSITE SYMBOL - The combination of symbol type ($\bullet$, S, or A) and
symbol designator ($\wedge$, $\sqcap$, or $\cap$) to form one symbol.

COUNTING QUESTIONS - Questions in which pilots were asked the number
of a specified symbol on the format.

GLOSSARY OF TERMS (Cont'd)

CRUISE FLIGHT SEGMENT - CRUISE is an A-7 flight mode used between CLIMB
and DESCENT.

HORIZONTAL SITUATION FORMAT (HSF) - The format located on the upper
center CRT. The HSF presented the combat situation symbology and
some navigation information.

KOLMOGOROV SMIRNOV TEST - A one-sample goodness of fit test to
determine if the distribution of a set of sample values differs
from the normal distribution. Used to analyze questionnaire
rating-scale data.

KRISHNAIAH FINITE INTERSECTION TESTS (FITs) - A set of tests conducted
after significant MANOVA results are found to determine: 1) which
of the dependent variables were most sensitive to changes in
independent variables; and 2) which of the experimental groups
differed significantly from each other.

MULTIVARIATE ANALYSIS OF VARIANCE (MANOVA) - A statistical procedure
which takes into account the fact that several partially correlated
dependent variables may be affected by experimental manipulation,
and which can determine significant differences in experimental
conditions.

RASTER-WRITTEN CRT - A CRT in which the picture is generated from the
top left corner to the lower right corner by a series of horizontal
actions.

ROOT-MEAN-SQUARE ERROR (RMS) - A summary statistic descriptive of the
error amplitude distribution of a sample of tracking performance.
Specifically, it is an index of performance variability that is
relative to the null point.

GLOSSARY OF TERMS (Cont'd)

SEARCHING QUESTIONS - Questions in which the pilots were required to
search for a specified symbol across all quadrants of the format.

SHAPE-CODING CONDITION - Experimental condition in which the symbols were
shape-coded only to denote their states.

SIMPLE QUESTIONS - Questions in which pilots were required to recognize
only symbol type and state. Half of each type of question
(Counting, Searching, Comparing) were simple.

STANDARD DEVIATION (SD) - A summary statistic descriptive of the error
amplitude distribution of a sample of tracking performance.
Specifically, it reflects the variability of dispersion of the
meansures around the central tendency (as indexed by the absolute
error or AE).

STROKE-WRITTEN CRT - A CRT on which vector graphic figures are drawn by
an electron beam much like they would be by a pen or pencil.

SYMBOL DENSITY LEVEL - Independent experimental variable in which one-
third of the HSF formats contained 10 symbols, one-third 20
symbols, and one-third 30 symbols.

SYMBOL STATE - Symbols could be in any of three states: hostile,
unknown, or firendly. In the shape-coded condition hostile symbols
were denoted by a $\wedge$ hat, unknown a $\sqcap$ hat, and friendly a $\cap$ hat.
In the color-coded condition hostile symbols were also red, unknown
yellow, and green friendly.

SYMBOL TYPE - There were three symbol types: anti-aircraft artillery
(AAAs), surface-to-air missiles (SAMs), and aircraft. AAA were
denoted by the sumbol A, SAMs by the symbol S, and aircraft by a ●.

GLOSSARY OF TERMS (Concluded)

WILCOXIN MATCHED-PAIRS SIGNED RANKS TEST - A statistical test which
utilizes information about the direction of the differences among
pairs to determine significance.

SUMMARY

The Department of Defense is currently working on a real-time combat situation display to be used in fighter aircraft cockpits. This study evaluated a symbology set for this type of display under simulated combat mission conditions. The primary purpose of the study was to compare pilot flight performance and symbol recognition performance using two different coding conditions: (a) one in which symbols were shape-coded only; and (b) one in which symbols were both shape- and color-coded. These two coding conditions were tested under three different symbol density levels: 10, 20, and 30 symbols. The addition of redundant color-coding to shape-coded symbols was found to reduce the overall average response time to symbology questions by forty percent. The effectiveness of redundant color-coding became more pronounced as the symbol density of the situation formats increased.

A secondary purpose of the study was to compare performance differences among the three symbol types (A for anti-aircraft, S for surface-to-air missile, and ◆ for aircraft) in each of the three symbol states (⧹for hostile, ⊓ for unknown, and ⌒ for friendly). The analyses found the 𝔸 and 𝕊 symbols required significantly longer times for identification than any other symbols. This is thought to be due to the state designators being parallel to the top of the letter in both cases. Subjectively the pilots disliked the 𝔸 symbol because: (1) it closely resembled a delta-shaped symbol (⋀) that in the past has been used to denote aircraft; and (2) they associate the letter A with aircraft rather than anti-aircraft artillery. The subjective data also revealed the pilots had some difficulty distinguishing the ⌒ and ⋀ state designators due to the characteristics of the raster display.

SUMMARY (Cont'd)

Performance differences as a function of question type and complexity were also examined.* The counting questions had significantly longer response times and a significantly higher error rate. The longer response time for counting questions is accounted for by the fact that the pilot had to do an exhaustive scan of the whole display for this type of question, whereas he did not for searching or comparing questions. This longer response time supports the use of subscripts to denote clusters of a particular symbol on a situation display--i.e. A_4. Complex questions did not take significantly longer to recognize nor did they have a significantly higher error rate. This finding, along with the fact that the pilots liked the use of aircraft symbol orientation to show heading, suggests that encoding three variables (type, state, and orientation) is both acceptable and usable.

* There were three question types: counting, comparing, and searching. There were two complexity levels: simple questions requiring recognition of symbol type and state, and complex questions requiring recognition of orientation as well.

SECTION I

INTRODUCTION

1. BACKGROUND

The feasibility of implementing a real-time combat situation
display in a fighter aircraft is currently being pursued by the
Department of Defense (DOD). Such displays would have vital threat
location information transmitted to them via a battle area communications
network consisting of satellites over, or aircraft and ships near, the
forward edge of the battle area. These communications networks would, of
course, be secure and jam resistant. The transmissions would be matched
with the inertial navigation system of each fighter aircraft, and the
resultant combat situation display would locate the threats in relation
to that aircraft's position.

One crucial step in the development of such a real-time situation
display is to devise a symbology set that can be used both with newer
aircraft coming into the DOD fighter inventory having head-down raster-
written cathode ray tubes (CRTs) such as the F-16 and A-10 and with the
current F-14 and F-15 aircraft which have a combination of stroke- and
raster-written CRTs.

The Flight Dynamics Laboratory implemented one such symbology set
on a simulator cockpit CRT having raster writing (see Table 1 for
symbology set). Each symbol conveyed three important details: 1)
whether it was an aircraft (●), surface-to-air missile (s), or anti-
aircraft artillery (A); 2) whether it was hostile ($\wedge$), unknown ($\sqcap$), or
friendly ($\cap$); and 3) in the case of an aircraft, its heading (12, 3, 6,
or 9 o'clock).

A factor of primary concern was whether the pilot of a fighter
aircraft could effectively use such a display during the heavy workload
situations found in combat. The questions were: 1) would the display
prove to be too complicated to be interpreted by the pilot; and 2) would
it be too much of a distraction from his primary flying and weapon

TABLE 1

SYMBOLOGY SET USED IN THE EVALUATION

Symbol	Height (mm)	Width (mm)	Type	State	Orientation
⌃	3	6	· (Aircraft)	⌃ (Hostile)	12 o'clock
⌄	6	3			3 o'clock
⌄	3	6			6 o'clock
⌃	6	3			9 o'clock
⌐·	3	6	· (Aircraft)	⌐ (Unknown)	12 o'clock
⌐	6	3			3 o'clock
⌐	3	6			6 o'clock
⌐	6	3			9 o'clock
⌢·	3	6	· (Aircraft)	⌢ (Friendly)	12 o'clock
⌢	6	3			3 o'clock
⌣	3	6			6 o'clock
⌢	6	3			9 o'clock
⌃S	6	6	S (Surface-to-air missile)	⌃ (Hostile)	12 o'clock
⌐S	6	6		⌐ (Unknown)	
⌢S	6	6		⌢ (Friendly)	
⌃A	6	6	A (Anti-aircraft artillery)	⌃ (Hostile)	12 o'clock
⌐A	6	6		⌐ (Unknown)	
⌢A	6	6		⌢ (Friendly)	

2

delivery tasks. This study provides both objective performance data from pilots using the display under simulated mission conditions, and pilot opinions on the usefulness of such a display under combat conditions. Pilots were given recognition tasks involving situation formats with density levels of 10, 20, and 30 symbols to simulate varying degrees of activity in the combat area.

Previous research in the area of displays has shown redundant color-coding (e.g. coding symbols both by shape and color) to significantly reduce both symbol recognition time and number of errors (References 1, 2, and 3). Therefore, one experimental condition of this study presented situation formats whose symbols were shape-coded according to state ($\wedge$ for hostile, $\sqcap$ for unknown, and $\cap$ for friendly), while a second condition also had each of the symbols additionally color-coded (red for hostile, yellow for unknown, and green for friendly).

However, despite this research supporting the use of color as a beneficial coding technique, not all research in the area has been favorable. Several authors have stressed that the impact of color-coding is highly situation-specific and may have neutral or even detrimental effects in given situations; the effect depends on a number of diverse factors such as operator task, display medium, or display environment (References 4 and 5). It has also been pointed out that most experiments investigating color-coding have used subjects who devoted their full attention to the display and performed single, relatively simple tasks (Reference 4).

2. PURPOSE

This experiment did not limit the function of the operator to the performance of one simple task at a time, nor did it dictate an optimal display environment or display medium. The study was designed to evaluate redundant color-coding for a real-time situation format in a fighter aircraft cockpit. Such a format would be used in somewhat peripheral manner by a highly-loaded pilot while performing complex

flight maneuvers. Thus, this study sheds some light on the effectiveness
of redundant color-coding for formats used by operators who are
performing a series of complex tasks which allow them little time to scan
the display.

Therefore, the primary purpose of this study was to compare pilot
flight performance and symbol recognition performance under simulated
flight conditions using two different coding conditions: (a) one in
which symbols were shape-coded only; and (b) one in which symbols were
both shape- and color-coded. These two coding conditions were tested
under three different symbol density levels: 10, 20, and 30 symbols.

A second factor examined in the study was the distinguishability of
the state designators ($\wedge$, $\sqcap$, and $\frown$) and the symbol types themselves
($\bullet$, S, and A). The state designators were of particular concern,
because as the aircraft symbols traveled there were distortions of the
raster-written state designators--particularly in the 3 and 9 o'clock
orientations.

SECTION II

TEST APPARATUS

1. COCKPIT SIMULATION

A fixed-base, single-seat cockpit of a A-7D dimensions was fabricated to accomodate electro-optical displays and a multifunction keyboard (MFK). Figure 1 shows the location of these devices within the cockpit. The canopy of the simulator was covered with a heavy black cloth during testing to simulate IFR conditions and eliminate any distractions to the pilot.
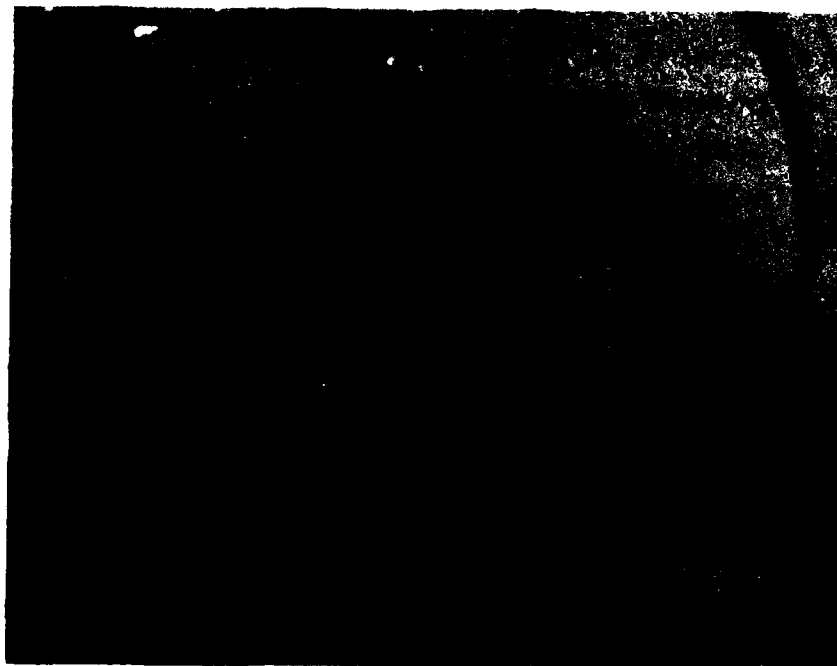
Figure 1. Fixed-Base, Single-Seat Cockpit Simulator

a. Electro-optical Displays

For this study the head-up display (HUD) and three of the five head-down displays were active (see Figure 2). All active displays were raster CRTs, and were named according to the type of formats which were presented on them for this particular study. The primary flight symbology appeared directly in the pilot's forward field-of-view on the HUD (see Figure 3). The horizontal situation format (HSF) was used to present the combat situation symbology and some navigation information. For use during the experiment, the face of the HSF was marked off into four quadrants, with the quadrant numbers clearly marked on the HSF bezel (see Figure 4). The order used in numbering the quadrants was determined by surveying a number of pilots, and implementing the order preferred by the majority. Relevant navigation, communications, and stores information appeared on the status format (SF) (see Figure 5). The multifunction keyboard (MFK) was used to present the current legends of the five multifunction switches located down each side of the display (see Figure 6). Further discussion of the MFK is deferred to subsection 1b of Section II. Comprehensive narratives of all four of the displays can be found in Appendix A.

b. Combat Situation Formats for the HSF

A total of 27 combat situation formats were generated for the experiment (see Appendix B for examples of formats). Three of these formats were used for the cockpit briefings, six for the training missions, and eighteen for the data missions. Within each of these three functional categories, one-third of the formats contained 10 symbols, one-third 20 symbols, and one-third 30 symbols.

Each format, regardless of density level, contained symbols for aircraft (●), SAMs (S), and AAAs (A). Each of the above symbols was augmented by a state designator: hostile (∧), unknown (⌐), or friendly (∩) (see Appendix B). In the color-coded condition, the hostile was also red, the unknown yellow, and the friendly green. A ratio of 1 S: 1A:3● and a ratio of 5 ∧ : 3⌐: 2∩ was maintained for each of the 27 formats. These ratios were chosen based on the perceived threat mix that a pilot may encounter in a tactical environment.
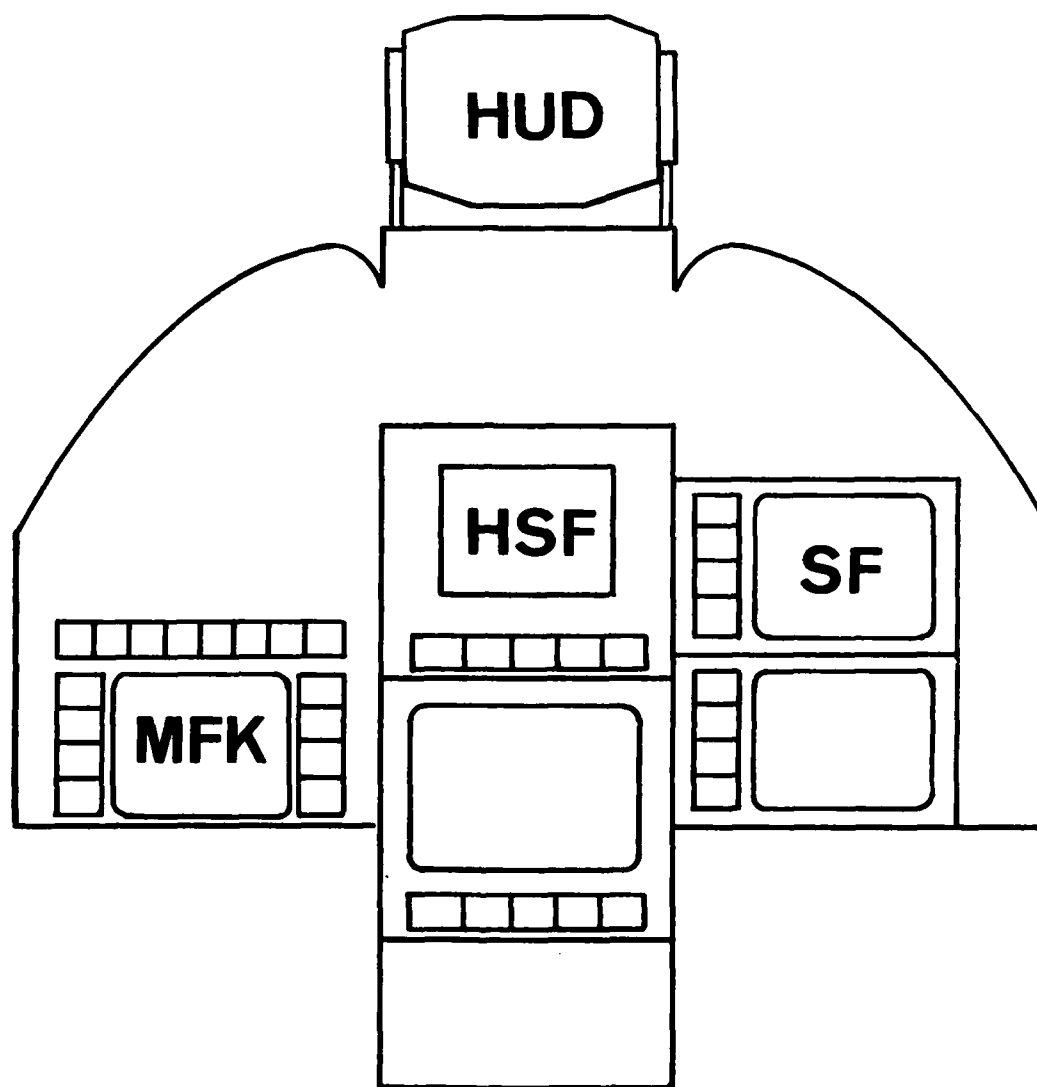
Figure 2.   Location of Electro-Optical Display Formats
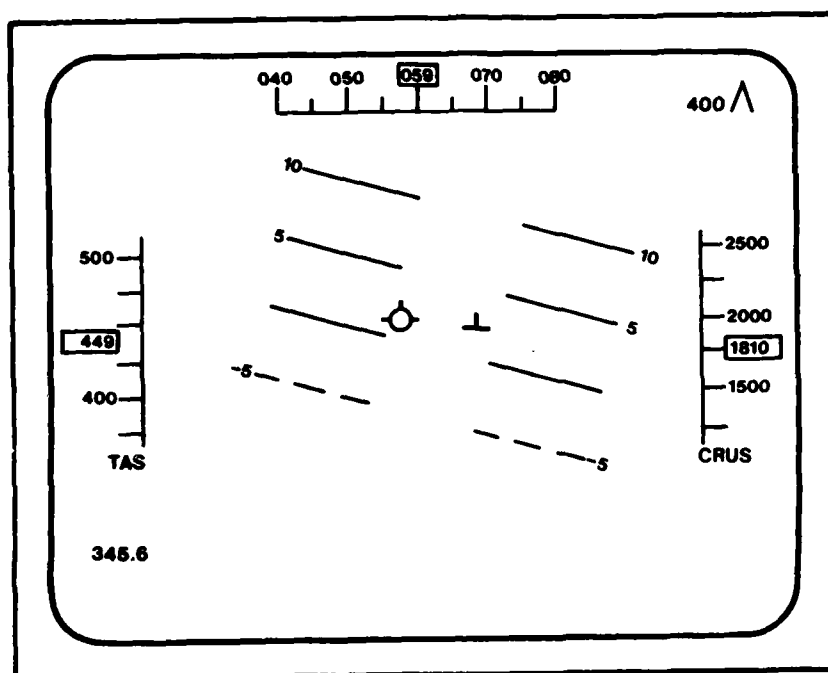
Figure 3. Head-up Display (HUD) Format

Figure 4. Horizontal Situation Format (HSF)

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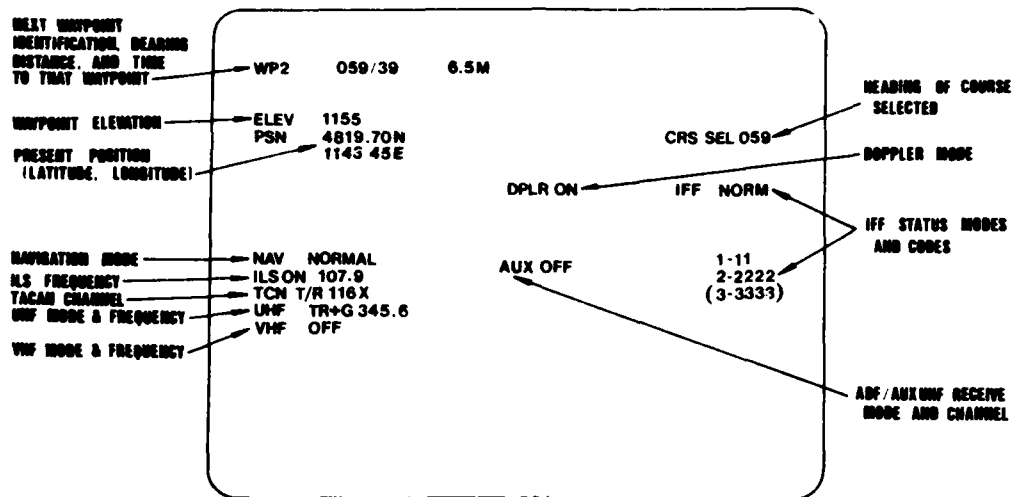
Figure 5. Status Format (SF)
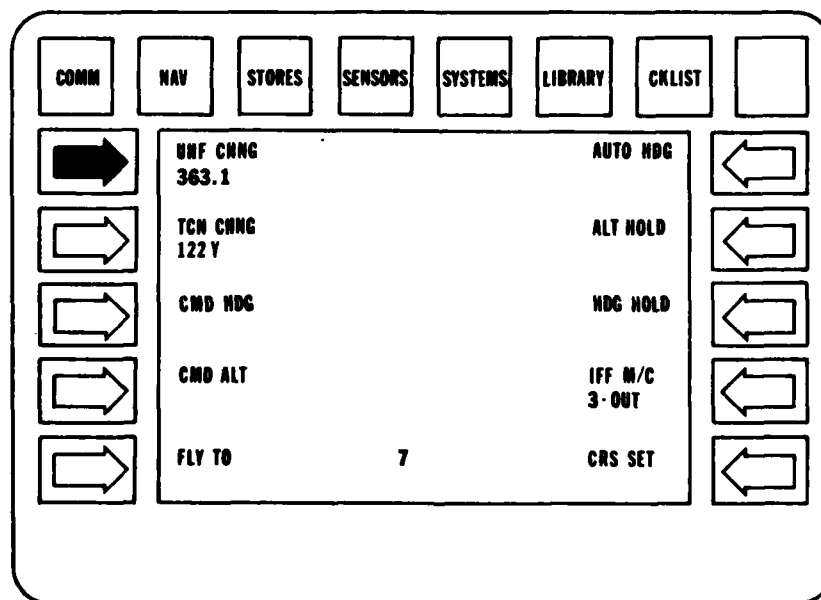
Figure 6. Multifunction Keyboard (MFK) for CRUISE Mode

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The symbol for SAMs (S) and AAAs (A) remained stationary in a fixed position relative to the inertial track and were presented in only one orientation--pointed toward 12 o'clock. The aircraft symbols (●) appeared in any of four orientations (12, 3, 6, or 9 o'clock) and traveled in that direction. Each aircraft orientation appeared an equal number of times across all formats. Because the pilot's aircraft symbol traveled along the inertial track, the combat situation format appeared to move toward the bottom of the display or the 6 o'clock position as the pilot flew along the groundtrack.

Each combat situation format represented a combat environment 80 nautical miles in length. The pilot's aircraft symbol was located at the center of the environment with a range of 40 nautical miles ahead of it. Symbol type, symbol state, aircraft symbol orientation, and the horizontal and vertical location of each symbol on the format were randomly assigned within the constraints of the experimental design so that the proper ratios among symbol types, symbol states, and aircraft orientations were maintained.

The formats were computer-generated, and were overridden by the groundtrack. The symbols on each format were prioritized according to the degree of threat they posed to the pilot's aircraft, and were programmed such that when two symbols crossed, the more lethal threat always overrode the lesser one. The descending order of lethality used was: hostile SAMs, hostile AAAs, hostile aircraft, unknown SAMs, unknown AAAs, unknown aircraft, friendly SAMs, friendly AAAs, friendly aircraft. Each symbol retained the same state of lethality throughout the missions. Symbols of interest, that is, symbols about which questions were to be asked, were checked out to insure that: 1) they did not run into another symbol(s); 2) they did not disappear off the display; and 3) for comparison type questions, they did not cross from one quadrant of the display into another.

c. Multifunction Keyboard (MFK) and Data Entry Keyboard
(DEK) Hardware

(1) MFK Hardware

The MFK hardware consisted of eight dedicated push-button
function select switches in a row across the top of the left CRT, and
five push-button multifunction switches down each side of the CRT (see
Figure 6). Seven of the eight function select switches were lighted
during the study, and their respective legends displayed on the switch
faces. The MFK was programmed according to a tailored logic based on
frequency of use. The ten multifunction switches controlled the ten
functions the pilot was most likely to require in the particular flight
segment he was in. The multifunction switches were operable to the pilot
only after the experimenter initiated a task event. They remained
operable until the task event was completed. The function select
switches across the top of the CRT were rendered inoperable to the pilot
because during the experiment the pilot was asked only to perform MFK
tasks which could be initiated directly from one of the ten active MFK
switches.

(2) DEK Hardware

A Data Entry Keyboard (DEK) consisting of twelve
dedicated push-button keys arranged in a 4 x 3 telephone layout was
located on the forward section of the left side console (see Figure 7).
The CLEAR and ENTER keys on the DEK appeared on the left and right sides
of the zero, respectively. In addition, the letters N, S, E, W, X, and
Y could be selected on the keys labeled 2, 8, 4, 6, 7, and 9
respectively. (The computer could discern whether letter or number data
entry was required, and therefore no shifting device was necessary.) The
DEK became operable and lighted when the task required the pilot to
enter digits, and remained in this condition until the ENTER key had been
pushed and the data accepted by the computer.

Figure 7. Data Entry Keyboard (DEK)

d. Dedicated Controls and Displays

Most of the backup flight instruments in the cockpit simulator were inoperable so that the pilot was forced to use the information displayed on the HUD and HSF to maintain control of the simulator. However, the following devices were operable and available for use by the pilot during the experiment:

a) Angle of Attack Indicator

b) Engine Instrumentation (RPM, Turbine Outlet Pressure, Fuel Flow Indicator, Turbine Outlet Temperature, Oil Pressure)

c) HUD Declutter Switch

d) Master Arm Switch

e) Control Stick and Rudders

f) Trim Button and Bomb Release Button on the Stick

g) Throttle

At the onset of the experiment, the cockpit displays were tailored to the cruise mode and the CRUISE flight segment switch located below the HUD was lighted. Appendix A provides a more complete description of the dedicated instruments and switches.

2. EXPERIMENTERS' CONSOLE

The experimenters' console provided repeater displays which allowed the experimenters to monitor the cockpit displays and provided status lights which allowed them to monitor the pilot's performance on MFK tasks (see Figure 8). A series of console push-button switches allowed the experimenters to control task initiation, task termination, data flight termination, and recording of task response times. The experimenters' console also contained a status display not found in the cockpit (see Figure 9). This display presented pertinent experimental details such as task type, mission task number, time into task, and elapsed time since mission start. Also presented were the digits programmed for the MFK tasks, the digits selected by the pilot, and the correct responses for the symbology questions. A Sony cassette tape recording device housed in the experimenters' console permitted the recording of voice transmissions.

3. PDP 11/50 KEYBOARD TERMINAL

The training and data missions were initialized through the PDP 11/50 terminal. The pilot's responses to the symbology questions were also entered through the terminal by one of three experimenters during the experiment.

4. ADDITIONAL FACILITY SYSTEM ELEMENTS

A functional description of each system element of the simulation facilities is given in Appendix C. This appendix also provides a layout and description of each piece of equipment on the experimenters' console.

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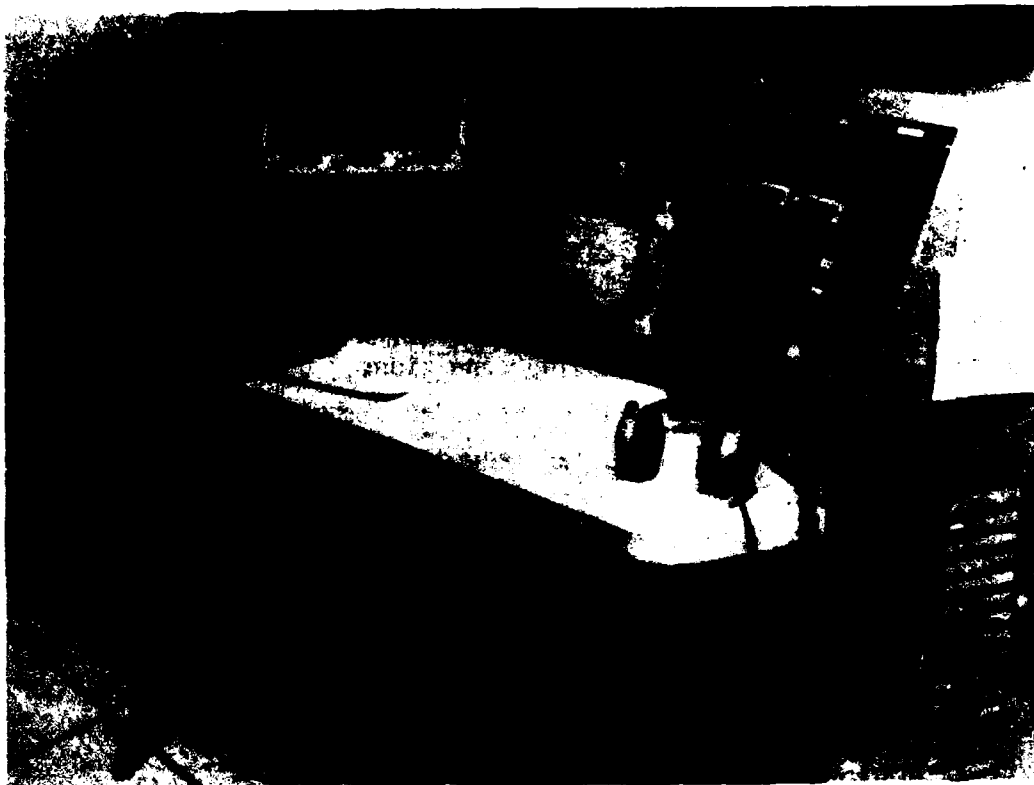
Figure 8. Experimenters' Console

Figure 9. Experimenters' Console Status Display

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SECTION III

TEST METHOD/APPROACH

1. TEST OBJECTIVE

The primary purpose of this study was to compare pilot flight
performance and symbol recognition performance under simulated flight
conditions using two different coding conditions. Under one condition
each of the situation formats had shape-coded symbols, while under the
other condition the same formats had redundant color-coding added to the
shape-coding.

A secondary purpose was to determine if performance differences
occurred between the two coding conditions as a result of increasing
situation format symbol density. To test this hypothesis, each of the
two coding conditions was tested under three symbol density level
conditions: 10, 20, and 30 symbols.

A third purpose was to examine the distinguishability of the
proposed symbol set's state designators and type designators when used in
combination. There were nine symbol combinations: A⃝, A⃝, ⬡ ,⌐A⌐,
⌐S⌐, ⌐●⌐, A⃝, S⃝, and ●⃝ .

Five objective performance measures were used in this study. Three
pertained to pilot flight performance--true airspeed deviation from 350
knots, and vertical and horizontal deviations from the commanded flight path;
and two pertained to symbol recognition performance--response time and
accuracy. Subjective measures were obtained through the use of three
debriefing questionnaires.

2. TEST DESIGN

Each pilot flew four thirty-minute data missions: two with
achromatic shape-coded situation format symbology, and two with color-
and shape-coded situation format symbology. Half of the pilots flew
missions with achromatic coding first, half flew missions with color-
coding first--pilots having been randomly assigned to one group or the other.

Each mission consisted of two flight segments (CRUISE and CCIP AUTO).
The data being reported in this technical report was collected only in
the CRUISE segment. After each pilot performed the final task for the
CRUISE segment, the CCIP AUTO segment was begun. During this segment
half of the pilots flew a modified pop-up maneuver using conventional A-7
like HUD symbology, while half of the pilots flew the same maneuver
using an experimental integrated HUD symbology. The results of this
segment, along with a follow-on study of the two HUD symbologies, were
reported separately (Reference 6). Therefore, the CCIP AUTO segment
will be mentioned only when necessary to clarify experimental details.

Each of the four data missions contained the same number and types
of tasks--nine symbology questions and six MFK tasks. With the exception
of the last task which was always a Weapons Option MFK task leading into
the CCIP AUTO segment, the order of the tasks was randomly assigned.
The order in which pilots were shown situation formats for each symbol
density level was determined by the use of a trend-free systematic design
(Reference 7). This method is appropriate when there are few treatment
levels and the levels are administered more than once to a subject.

3.   TEST SUBJECTS

A total of eighteen A-7 pilots served as subjects in this
experiment. They had an average of 2305 flying hours, with an average
of 493 hours in the A-7D. Half of the pilots flew with the 121st
Tactical Fighter Wing (ANG) at Rickenbacker AFB and half with the 178th
Fighter Group (ANG) at the Springfield Municipal Airport, Springfield,
Ohio.

4.   TEST PROCEDURE

a.   Home-Base Pilot Briefings

Prior to the experiment, the members of the experimental team
traveled to each of the Air National Guard units to give the subjects an
initial briefing. Throughout the two briefings the procedures were
standardized such that each pilot received the same information and

opportunity for familiarization with the purpose of the experiment, the procedures that would be used, the cockpit simulator, and the types of symbology questions and MFK tasks they would be asked to perform. The initial briefing sought to familiarize the pilots with the relevancy of the experiment with regard to future fighter systems, to acquaint them with the advanced "digital" aircraft concept and the simulator cockpit controls and displays, and, finally, to introduce them to the Tailored Logic used to complete each type of MFK task.

Following the group briefing, short training sessions on MFK Tailored Logic was held. Using a mockup of the simulator MFK composed of a random access slide projector and a control panel, one experimenter demonstrated the progression of logic levels for each type of task. A briefing package illustrating each MFK task logic sequence was given to each pilot for further study.

b. On-Site Pilot Briefings

After the home base training, each pilot traveled to Wright-Patterson AFB for the on-site cockpit simulator briefing, training, and testing. The information explained or demonstrated during the briefing was as follows:

1) Unique aspects of the simulator as compared to the A7

2) Flight segments and the HUD symbology to be flown

3) Flight performance measures and symbology recognition performance measures being taken

4) The order of the test flights

5) HSF format (including combat situation symbology and the different density levels)

6) Procedure for answering symbology questions and examples of each type of question (see Figure 10)

7) MFK and DEK operation for each type of MFK task (including clear function and correction procedures and error messages) (see Table 1)

8) Status formats

9)   Use of the throttle, rudder pedals, trim switch, bomb release button, backup flight instruments, flight mode switches (inoperable), intercomm system, brightness controls, master arm switch, hydraulic abort switch, cockpit exit procedures, flight gloves, and flight plans

10)   CCIP weapon delivery details.

After the experimenter concluded the briefing, the pilot was allowed to practice the symbology questions and MFK tasks while the simulator was in a "hold" condition. Following this practice session, the pilot was given a few minutes to practice flying the simulator. A fifteen-minute break followed the cockpit briefing and pilot practice session.

c.   Training Flights

The first achromatic-coded mission was preceded by a 20-minute achromatic training flight containing each type of symbology question and MFK task to be given in the data missions. A similar training flight using both color- and shape-coding was given before the first color data mission.

d.   Data Flights

(1)   Mission and Tasks

Four missions involving simulated flight in the CRUISE segment were used. (Additional mission information and the initial conditions for one of the missions are provided in Appendix E.) Throughout each flight, the symbology and information displayed on the HUD and HSF were dynamic in response to thrust, bank, yaw, and pitch inputs. The groundtracks did not involve any turns greater than 35 degrees, nor altitude changes greater than 4,000 feet. Information on the status format was updated in response to aircraft position and data inputs on the MFK.

The pilot's flying task during the CRUISE portion was to maintain a true airspeed of 350 knots and to keep the flight director

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symbol centered on the HUD. The symbology questions asked involved either counting particular symbols on a format, searching for the location of a specific symbol, or comparing specified symbols in two quadrants. The MFK tasks given the pilot involved either communications, navigation, or stores management functions. The symbology questions and MFK tasks were felt to be typical tasks a pilot would perform during a mission in a single-seat fighter equipped with a real-time situation display. The fact that flying performance, symbology question performance, and keyboard operation performance were all to be recorded was stressed to the pilots.

Each mission contained nine symbology questions and six MFK tasks randomly ordered (see Table 2). Mission scenarios were constructed around each set of randomized tasks in order to provide a high degree of external realism. In this way, the task orders appeared logical. The task instructions were given over the headset using standard controller terminology (see Appendix F for example of a mission script text).

(a) Symbology Questions and Corresponding Formats

A total of 36 symbology questions were written--two questions per situation format. Each pilot received all 36 questions, and so was exposed to each of the 18 formats twice. However, the experiment was designed such that a pilot received each format only once in each coding condition. Thus, he saw each format once in the morning and once in the afternoon. Each symbology question and its corresponding situation format were viewed in both the achromatic and color conditions.

During each mission a pilot received a counting question, a comparing question, and a searching question at each of the three density levels. Across a two-mission series of the same coding conditions, the pilot received each one of the above questions in the simple form in which he was required to recognize symbol type and state. He also received each in the complex form in which he was required to recognize orientation as well as symbol type and state (see Figure 10).

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TABLE 2

THE SYMBOLOGY QUESTIONS AND MFK TASKS (IN ORDER)
FOR TWO OF THE DATA MISSIONS

Task Number	Mission 5	Mission 11
1	Search (simple) for A s	Change UHF to 303.4
2	Count (complex) ♠ heading 12 o'clock	Search (simple) for A s
3	Change UHF to 348.0	Search (complex) for ♠ heading 6 o'clock
4	Search (simple) for S s	Change TACAN to 125Y
5	Compare (complex) quadrants 1 and 4 for most ♠ heading 12 o'clock	Squawk IFF Mode 3 in, and change code to 3600
6	Compare (complex) quadrants 1 and 4 for most ♠ heading 6 o'clock	Search (complex) for ● heading 3 o'clock
7	Squawk IFF Mode 3 in, and change code to 3700	Count (simple) ♠
8	Compare (simple) quadrants 3 and 4 for most ●	Compare (complex) quadrants 1 and 3 for ● heading 3 o'clock
9	Change IFF Mode 3 to 2100	Count (complex) ♠ heading 9 o'clock
10	Change TACAN to 115X	Compare (simple) quadrants 1 and 2 for A s
11	Search (complex) for ● heading 12 o'clock	Change IFF Mode 3 to 4100
12	FLY TO Waypoint 9	Compare (simple) quadrants 1 and 2 for ♠
13	Count (simple) A s	Count (simple) ●
14	Count (complex) ♠ heading 9 o'clock	FLY TO Waypoint 6
15	Select Weapon Option 2	Select Weapon Option 4

COUNT QUESTIONS I TOTAL DISPLAY I

● HOW MANY ⌃ ARE THERE? (SIMPLE)
● HOW MANY ⌃ HEADING AT 6 O'CLOCK? (COMPLEX)

SEARCH QUESTIONS I TOTAL DISPLAY I

● IN WHICH QUADRANT IS THE ⌃ LOCATED? (SIMPLE)
● IN WHICH QUADRANT IS ⌒ HEADING AT 12 O'CLOCK? (COMPLEX)

COMPARE QUESTIONS

● DOES QUADRANT 1 OR 2 HAVE MORE ⌃? (SIMPLE)
● DOES QUADRANT 3 OR 4 HAVE MORE ⌐ HEADING AT 3 O'CLOCK? (COMPLEX)

Figure 10.   Types of Symbology Questions

(b) MFK Tasks and Tailored Logic

During the study only Tailored MFK Logic was used.
In Tailored Logic the ten most likely control functions to be used in the
current flight mode are active and available to the pilot through the
five push-button multifunction switches on each side of the MFK CRT. All
of the MFK tasks corresponded to one of these ten available functions.
The first five tasks were given during the CRUISE mode, while the sixth,
the Weapon Option Selection task, occurred at the beginnning of the CCIP
AUTO mode (see Figure 6 and 11 for the CRUISE and CCIP AUTO MFK first
pages, respectively). Table 3 lists the six types of MFK tasks and the
switch hits required to accomplish each.
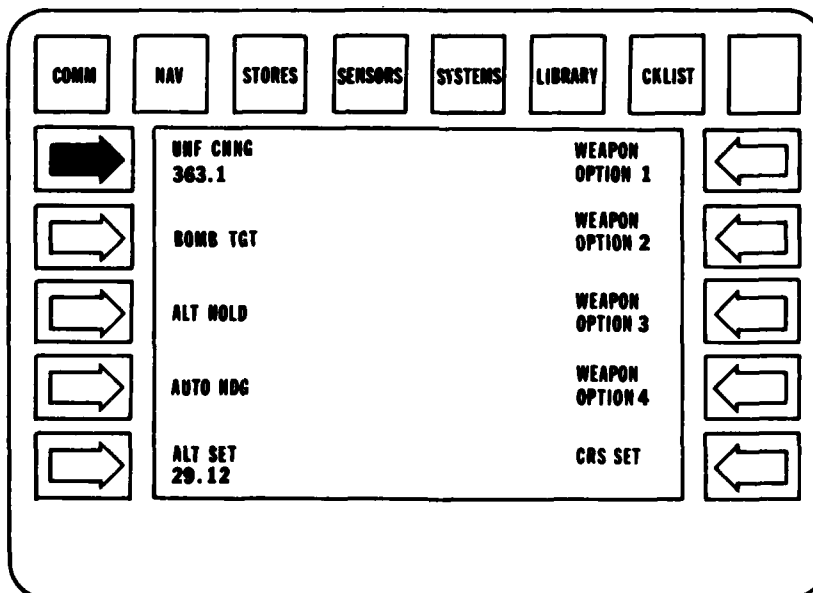
Figure 11.   Multifunction Keyboard (MFK) for CCIP AUTO Mode

TABLE 3

MFK TASKS AND THEIR OPERATING SEQUENCES

1.   <u>UHF Frequency Change</u>.
     The pilot had to select the UHF CHNG multifunction switch on the MFK, four digits on the DEK, then ENTER on the DEK.

2.   <u>IFF Mode 3 Change</u>.
     The pilot had to select the MODE 3 multifunction switch on the MFK, four digits on the DEK, then ENTER on the DEK.

3.   <u>IFF Mode 3 Change and Mode 3 In</u>.
     This was the only MFK task consisting of two subtasks.

     <u>Subtask a: IFF Mode 3 Change</u>. See above description of Task 2.

     <u>Subtask b: IFF Mode 3 In</u>. The pilot had to select the MODE 3 multifunction switch on the MFK, then ENTER on the DEK.

4.   <u>TACAN Channel Change</u>.
     The pilot had to select the TCN CHNG multifunction switch on the MFK, three digits and one letter on the DEK, then ENTER on the DEK.

5.   <u>FLY TO (Waypoint Number)</u>.
     The pilot had to select the FLY TO multifunction switch on the MFK, one digit on the DEK, then ENTER on the DEK.

6.   <u>Weapon Selection</u>.
     The weapon selection MFK task was always the last task before the CCIP AUTO pop-up maneuver. Prior to the weapon selection, the track was advanced to the beginning of the second flight segment and the CCIP tailored page appeared on the MFK (see Figure 11).

     The pilot then had to select the appropriate WPN OPTION multifunction switch on the MFK. This completed the task. However, before the weapon(s) could be released the pilot had to turn on the Master Arm Switch.

(2) Prodedures

Two of the three experimenters were stationed at the experimenters' console inside the testing room and monitored pilot performance, while the third experimenter was stationed at the computer terminal. Experimenter #1 was tasked with initiating pre-event periods, initiating and controlling task sequences and data recordings, and terminating training and data flights. Experimenter #2, an experienced fighter pilot, gave the cockpit briefing and demonstration prior to testing. During the training and data missions, Experimenter #2 played the role of a mission controller--reading from a scenario script constructed for each mission. The third experimenter was responsible for initiating the appropriate missions, entering responses to symbology questions, ensuring data recording on magnetic tape, and generally monitoring the computer operations. Flow diagrams of the procedural steps for symbology questions and MFK tasks discussed in the following paragraphs are shown in Figures 12 and 13 respectively. Basically, the procedural steps were broken down into four distinct stages or periods: pre-event, task event instruction, task event, and post-event. During the pre-event, thirty seconds of flight performance data were recorded. This flight performance data was designated as baseline performance, and was substracted from the pilot's flight performance data during the task event. This difference score quantified the level of flight performance during the task. Details of how this was done are discussed in the final subsection in the Section. During the task event instruction period the pilot received verbal instruction from Experimenter #2 and responded that he understood the task. The event period for the MFK tasks consisted of the time it took the pilot to correctly perform the task. (Note this included the time required to make any corrections.) For the symbology questions, the event period covered only the time it took the pilot to give his first response--whether it was correct or incorrect. A fourth period, the post-event, existed only for the symbology questions. During this time period, any errors made were identified and the correct response given to the pilot.

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E PUSHES PRE-EVENT SWITCH: RECORDS 30 sec

E NOTIFIED PRE-EVENT COMPLETE

E READS THE QUESTION TO S

S ROGERS THE QUESTION

NEW DISPLAY APPEARS ON HSF

RECORDING STARTS/ ELAPSED TIME SHOWN

S ANSWERS QUESTION VERBALLY

DOES S ANSWER QUESTION WITHIN 30 sec ?

NO

YES

E PUSHES TASK ABORT SWITCH

RECORDING STOPS/ RESPONSE TIME RECORDED

TERMINAL PROMPTS E TO INPUT RESPONSE

E INPUTS RESPONSE

S LOOKS AT HSF AND GIVES FEEDBACK

RECORDING STOPS/ 30 second RESPONSE TIME RECORDED

TERMINAL PROMPTS E TO INPUT RESPONSE

E INPUTS ZERO RESPONSE

E INFORMS S OF CORRECT RESPONSE

E RECORDS FEEDBACK

EVENT OVER

WAS RESPONSE CORRECT ?

NO

YES

EVENT OVER

E INFORMS S OF CORRECT RESPONSE

S LOOKS AT HSF AND GIVES FEEDBACK

E RECORDS FEEDBACK

EVENT OVER

Figure 12. Flow Diagram for Symbology Questions
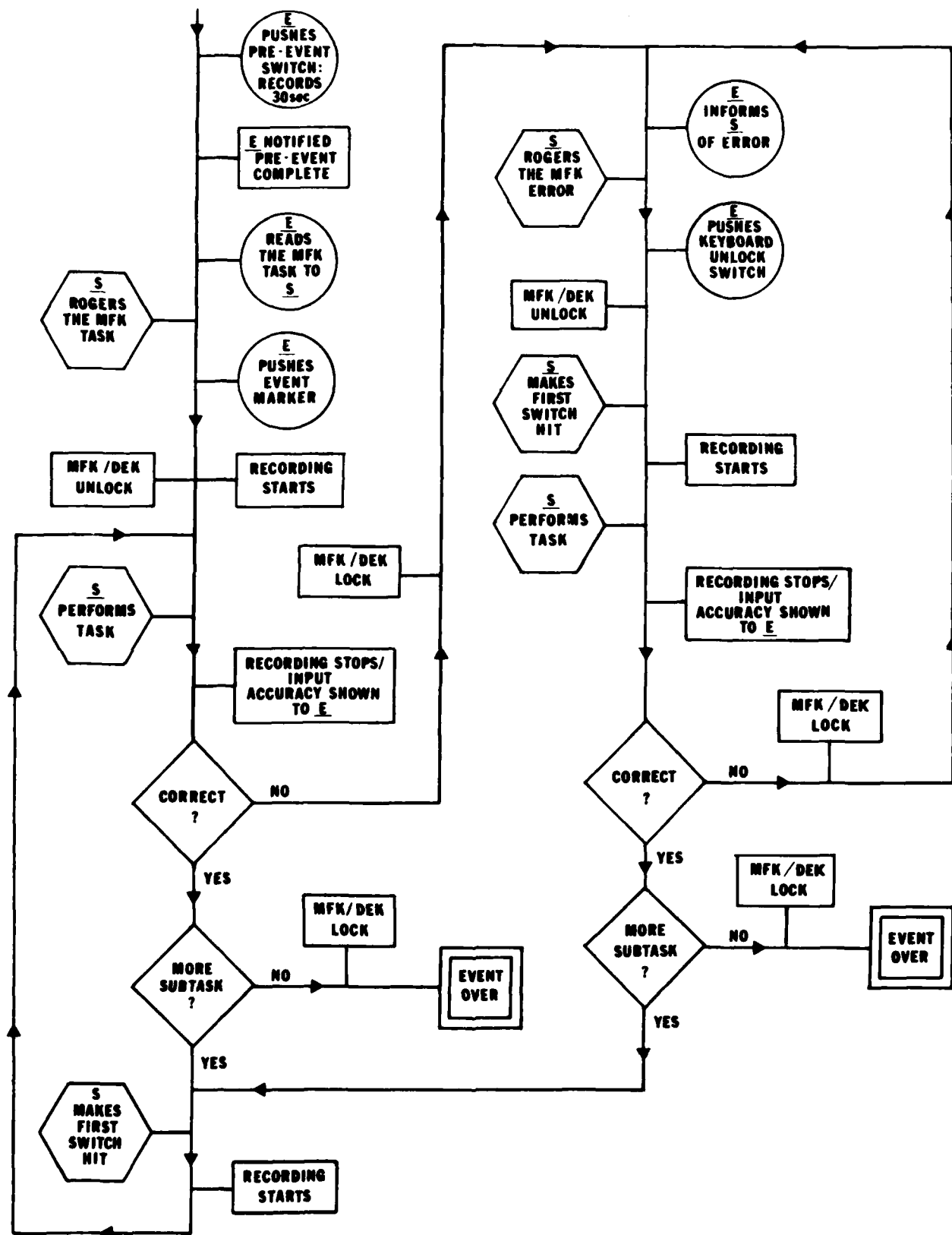
Figure 13. Flow Diagram for MFK Tasks

(a) Pre-event Period of Baseline Flight
Performance for Symbology and MFK Tasks

Experimenter #1 pushed a PRE-EVENT switch on the
console which started a thirty-second timer. Activation of this switch
automatically designated the beginning and end of the pre-event period of
baseline flight performance. The PRE-EVENT switch remained lighted
during the pre-event period. Concurrently, a countdown by seconds was
displayed on the experimenters' status display. When the displayed
countdown reached zero, the zero flashed until Experimenter #1 initiated
the task.

(b) Task Event Instruction Period for
Symbology and MFK Tasks

Once the thirty second pre-event period of baseline
performance had been recorded (PRE-EVENT switch light off, countdown
"zero" flashing), Experimenter #2 read either a symbology question to the
pilot or a command to accomplish an MFK task. (The experimenters
avoided initiating tasks when the pilot would have to complete the task
while flying a turn on the groundtrack.) Experimenter #2 read from the
written script to ensure the pilots received identical instructions for a
particular task and mission (see Appendix F). A verbal response from
the pilot was required to ensure that he understood the task. Using
these procedures, time to request a task or to acknowledge the
instruction was not a part of the pre-event or task event time.

The information required by the pilot to complete
the MFK tasks was provided on modified Flight Plans (AF Form 70s) and
was referenced during the instructions by the corresponding letter, or
number (see Appendix G for an example Flight Plan). The following were
identified by a letter or number on the Form 70: UHF frequencies, IFF
codes, altimeter settings, ILS frequencies/courses, waypoint identifiers,
and TACAN channels. Weapon parameter information was identified by
weapon option numbers. By identifying the information in this way,
errors due to faulty communication or forgetting of the information were
minimized.

(c) Task Event Period and Post Period for
Symbology Tasks

Concurrent with the pilot's acknowledgement of the
instructions, Experimenter #1 pushed an EVENT MARKER switch on the
console to initiate the task. If the task was a symbology question, this
switch action: 1) lit up the EVENT MARKER switch; 2) displayed new
format appropriate to that question on the HSF; 3) started a 30-second
timer on the console status display; and 4) initiated recording of flight
parameters. If the pilot answered, either correctly or incorrectly,
before the thirty seconds were up, Experimenter #1 pushed the TASK ABORT
switch on the console immediately to record response time and terminate
the recording of flight parameters. Response time was automatically cut
off after 30 seconds. Experimenter #3 then entered the pilot's first
response through the terminal after the thirty seconds were up. The
EVENT MARKER switch light extinguished upon entry of the pilot's response
through the terminal. If the pilot made an error, Experimenter #2
informed him of the error and the correct response. This frequently
prompted the pilot to provide valuable information on which of the
symbol(s) he had mistaken or which symbol location(s) he had overlooked
(see pilot comments in Appendix H). The response accuracy was also
available from the voice recording of the task instructions and the
pilot's response. The tape recording of the testing session could be
used to verify experimenter recorded data.

(d) Task Event Period for MFK Tasks

As with the symbology question procedure,
Experimenter #1 pushed the EVENT MARKER switch on the console when the
pilot acknowledged the task. This action: 1) lighted the EVENT MARKER
switch; 2) unlocked the cockpit MFK; 3) started the console timer; and
4) started the recording of flight parameters and MFK task data. The
EVENT MARKER switch light went out after successful completion of the
task event or when the TASK ABORT was selected. Activation of the TASK
ABORT switch on the experimenters' console terminated recording of the
MFK task and provided the experimenters with the capability to initialize
the pre-event period for the next programmed task. This switch was only

used during an MFK task if the experimenters determined that the data
being recorded was unusable and that the task would eventually have to be
rerun. Refer to Appendix A for a complete description of the MFK
operating procedures and control logic. For a listing of the specific
MFK tasks given, see Table 3.

(e) Mission Completion

After the pilot successfully completed all the
required tasks for the flight, Experimenter #1 terminated the flight by
pushing the MISSION COMPLETE switch on the console. After the flight had
been terminated, the summary statistic program was run to insure that
all of the data had been recorded. If the simulation facility broke
down during testing, or the data recording malfunctioned, the capability
existed to record data for any single task without rerunning the whole
data flight. The scoring program recognized only completed blocks of
data and ignored any incomplete task data.

(f) Pilot Debriefing

Immediately after the two consecutive data missions
using one symbology format coding condition, the pilots were given a
debriefing questionnaire concerning that coding condition. Following the
completion of all data flights, pilots were given a final overall
debriefing questionnaire, eliciting comparisons of the two types of
symbol coding. The cover page of the final debriefing questionnaire also
contained a number of questions about the pilot's flying experience and
background (see Appendix H for all three debriefing questionnaires).

(g) Performance Measures and Data Analysis

The pilot's performance in terms of flying the
simulator, answering the symbology questions, and performing MFK tasks
was measured. For the purpose of this report, only the flight
performance data and symbology question data were analyzed.

The following three flight parameters were recorded two times per second on magnetic tape:

a) True airspeed deviation (knots):

b) Flight director horizontal steering error (pixels); and

c) Flight director vertical steering error (pixels).

Appropriate summary statistics (average error, AE; average absolute error, AAE; root-mean-square error, RMS; standard deviation, SD) were computed on these flight parameters for:

a) The thirty second period prior to each task event (pre-event period); and

b) The time period between EVENT MARKER switch selection and TASK ABORT switch selection.

The thirty second pre-event time was designated as baseline performance. Summary statistics for the pre-event time for each parameter were substracted from the corresponding values computed for the time period required by the pilot to complete an assignment task event. This difference score quantified the flying task performance during the symbology tasks.

Symbology task performance was also evaluated by measuring:

a) Response time for each of the questions; and

b) Number of question errors

Two of the question types required the pilot to respond with a quadrant number (search and comparison), while the third required a numerical answer (count). When Experimenter #3 entered the pilot's response to a symbology question, the computer recorded a "1" for a correct response or "-1" for an incorrect response.

The RMS values for the three flight performance variables and the response time were initially analyzed by multivariate analysis of variance (MANOVA) using the SPSS (Statistical Package for the Social

Sciences) MANOVA program available on the CDC 6600 Computer System
(Reference 8). (Error data was not included in the MANOVA since the
computation method among questions types differed.) In those cases where
the MANOVA revealed significant effects, subsequent Finite Intersection
Tests (FITs) were conducted in order to determine: 1) which of the
dependent variables were most sensitive to changes in independent
variables; and 2) which of the experimental groups differed significantly
from each other (Reference 9).

Wilcoxin matched-pairs signed-ranks tests and Friedman two-way
analyses of variance (ANOVAs) by ranks were used to analyze error data
(Reference 10).

Data obtained from the debriefing questionnaires was compiled to be
presented in tabular form and appropriate nonparametric analyses were
conducted. Descriptive statistics were computed on the biographical data
obtained from the flight experience questionnaire to obtain an overall
sample view of the characteristics of the pilot sample. Nonparametric
Kolmogorov-Smirnov tests of significance were used to analyze the
questions involving rating scales (Reference 10).

SECTION IV

RESULTS

In this Section the results of the data analyses of the objective performance measures will be presented. (A significance level of α = 0.05 was set for each of the analyses.) The nonparametric analyses of the subjective questionnaire data will be presented as appropriate in the following section.

Performance differences between the two coding conditions at each of the three symbol density levels will be presented first. This will be followed by the performance differences among the three symbol types in each of the three symbol states. Last, performance differences among the three task types and differences between simple and complex tasks will be reported.

1. PERFORMANCE DIFFERENCE BETWEEN CODING CONDITIONS AT
   EACH DENSITY LEVEL

Performance differences between the achromatic shape-coding condition and the redundant color- and shape-coding condition were analyzed for each of the three density levels: 10, 20, and 30 symbols.

The MANOVA examining flight performance data and response time data found significant main effects for both coding condition and density level, F (4,14) = 17.40, p < 0.00003, and F (8,64) = 6.93 p < 0.00001, respectively. A significant interaction effect was also found between coding condition and density level, F (8,64) = 2.38, p < 0.03. The FIT analyses indicated that response time was the performance measure most affected by varying the independent variables. As shown in Figure 14, as the density level of the formats increased, the mean response times were increasingly faster with the redundant color-coding than with the shape-coding alone. Specifically, the FIT analyses revealed that performance was significantly better with the redundant color-coding at all three density levels: DL 10 (F (1,99) = 10.782, p < 0.003; DL 20 (F (1,99) = 37.123, p < 0.003); and DL 30 (F (1,99) = 33.747, p < 0.003). A FIT

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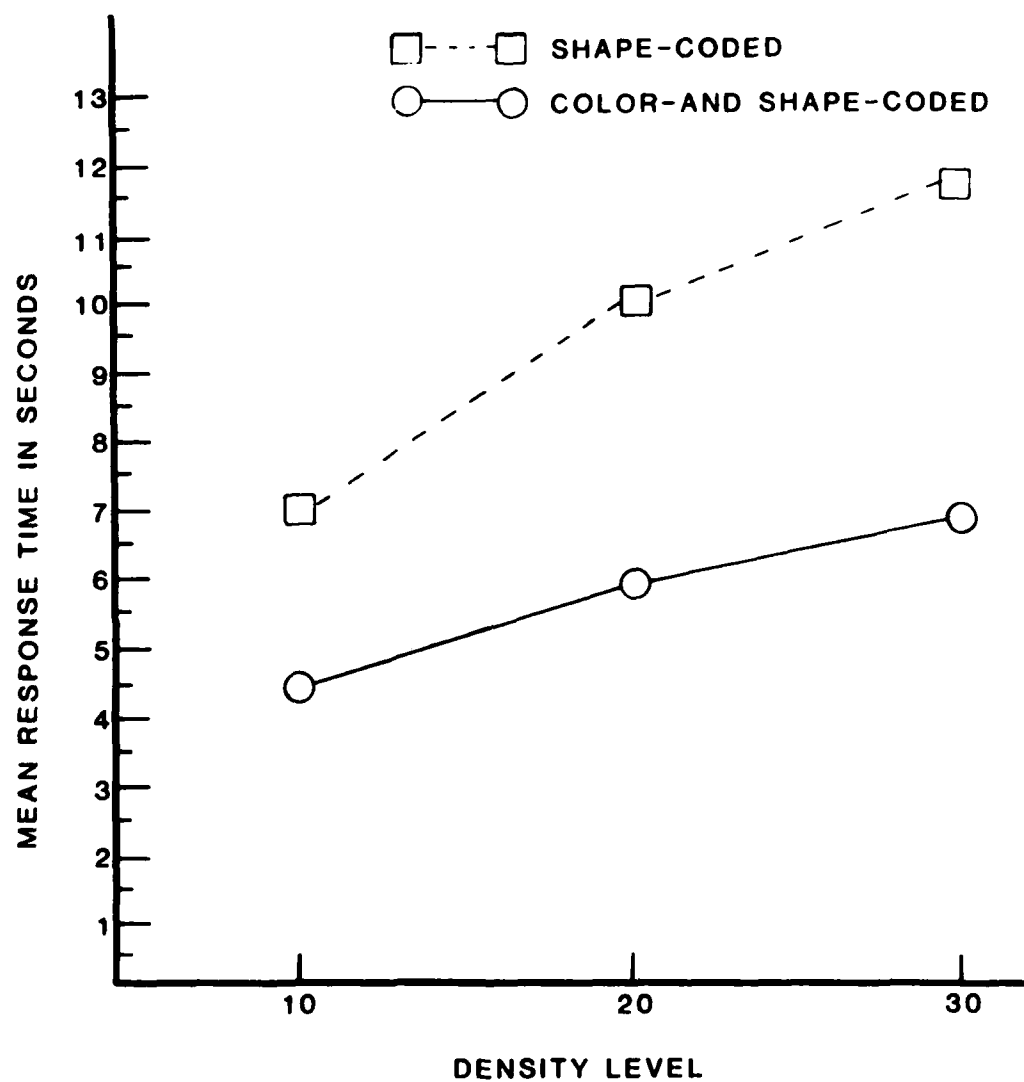
Figure 14. Mean Response Time for Each Coding Condition

analysis found no significant difference between redundant color-coding at density level 30 and shape-coding at density level 10. The difference in response time between these two conditions was less than one second.

The Wilcoxin test used to analyze the error data found significantly fewer errors in the redundant color condition at density level 30 only, $\underline{T}$, (11) = 3.5, $\underline{p}$ < 0.05 (see Figure 15). Although not significant, there were also fewer errors with redundant color-coding at density level 20. At density level 10 there was an error reversal where the color-coding condition had more errors than the shape-coding condition. The reasons for this reversal will be explored in the following section.

2. PERFORMANCE DIFFERENCES BETWEEN THE SYMBOL TYPES IN EACH STATE

Performance differences for each of the three types of symbols (●, S, and A) under each of the three states (∧, ⊓, and ⌒) were also examined. As in the previous MANOVA (subsection 1 of Section IV, paragraph 2), only flight performance measures and response times were included as dependent variables. Significant main effects were found for both symbol type ($\underline{F}$ (8,64) = 2.52, $\underline{p}$ < 0.02), and symbol state ($\underline{F}$ (8,64) = 2.25, $\underline{p}$ < 0.03). In addition, a significant interaction effect was indicated between symbol type and state, $\underline{F}$ (16,272) = 3.17, $\underline{p}$ < 0.00005. As was the case in the earlier MANOVA, response time was the performance measure most affected by varying the independent variables.

Figure 16 presents the response time for each symbol type as a function of symbol state. The Ⓐ symbol combination had, by far, the longest mean response time. The FIT analyses found it to differ significantly from all of the other symbols combined, $\underline{F}$ (1,153) = 41.13, $\underline{p}$ < 0.05, and from its nearest neighbor the Ⓢ, (the symbol with the next longest mean response time), $\underline{F}$ (1,153) = 4.66, $\underline{p}$ < 0.05.
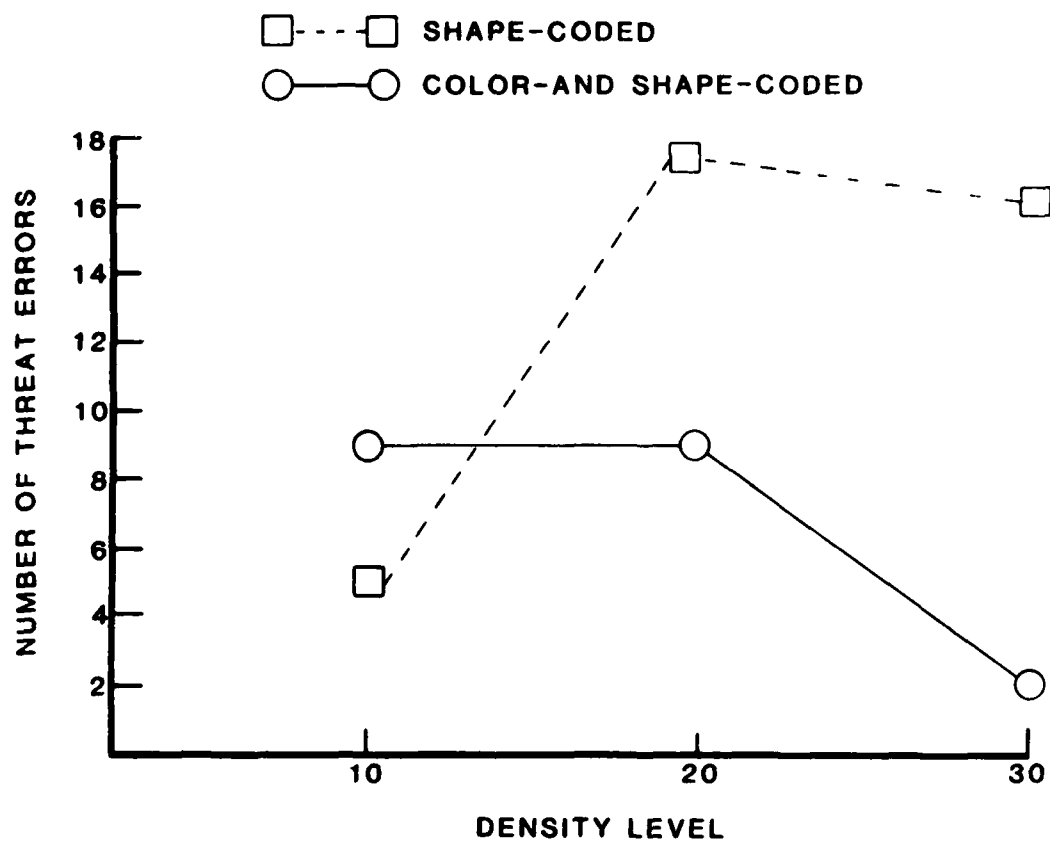
Figure 15. Number of Threat Errors for Each Coding Condition as a Function of Density Level
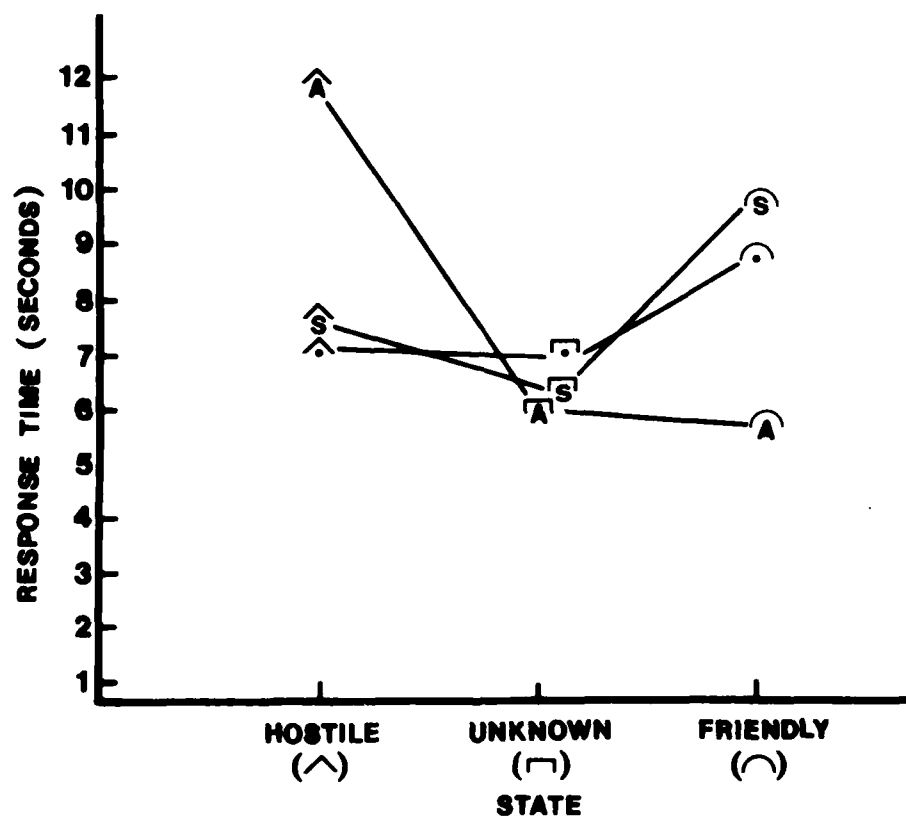
Figure 16.   Response Time for Each Symbol Type as a Function
of Symbol State

FIT analyses found the $\widehat{S}$ symbol to differ significantly from all of the other symbols combined, $\underline{F}$, $(1,153) = 10.08$, $\underline{p} < 0.05$. An additional analysis found the only symbol combination it did not differ significantly from was the $\textcircled{\bullet}$.

Threat error data could not be analyzed by parametric tests because there were unequal numbers of observations for the various symbol states and types. Table 4 gives the number of errors for each state and type, the number of observations, and the percentage of errors. Figure 17 presents the information graphically.

3. PERFORMANCE DIFFERENCES AMONG THE TYPES OF SYMBOLOGY
   QUESTIONS AT EACH COMPLEXITY LEVEL

An additional MANOVA was run comparing flight performance and response time data for aircraft counting questions, comparison questions, and searching questions at each of two complexity levels. One complexity level called the simple form required recognition of aircraft symbol type and state, while the second level called the complex form required recognition of aircraft symbol orientation as well.

The MANOVA revealed a significant main effect for question type, $\underline{F}$ $(8,64) = 5.12$, $\underline{p} < 0.0006$, but no main effect for complexity level ($\underline{p} < 0.07$). A significant interaction effect was found between question type and complexity level, $\underline{F}$ $(8,64) = 2.27$, $p < 0.03$. Follow-up FIT analyses revealed response time to be the performance measure that differed most among the question types (see Figure 18). Simple count questions were found to take significantly longer to answer than both simple search questions, $\underline{F}$ $(1,99) = 22.29$, $\underline{p} < 0.002$, and simple compare questions, $\underline{F}$ $(1,99) = 16.48$, $\underline{p} < 0.002$. Complex count questions were found to take significantly longer to answer than complex compare questions only, $\underline{F}$ $(1,99) = 15.06$, $\underline{p} < 0.002$.

TABLE 4

ERROR DATA FOR EACH SYMBOL TYPE UNDER EACH SYMBOL STATE

SYMBOL	NUMBER OF ERRORS	NUMBER OF OBSERVATIONS*	PERCENTAGE ERROR RATE
.	20	270	7.4%
.	21	138	15.2%
.	9	54	16.6%
A	4	36	11.1%
A	0	18	0.0%
A	1	18	5.5%
S	2	54	3.7%
S	1	36	2.8%
S	0	18	0.0%

* Six additional observations were taken on a question involving all aircraft on a format regardless of state (not included).
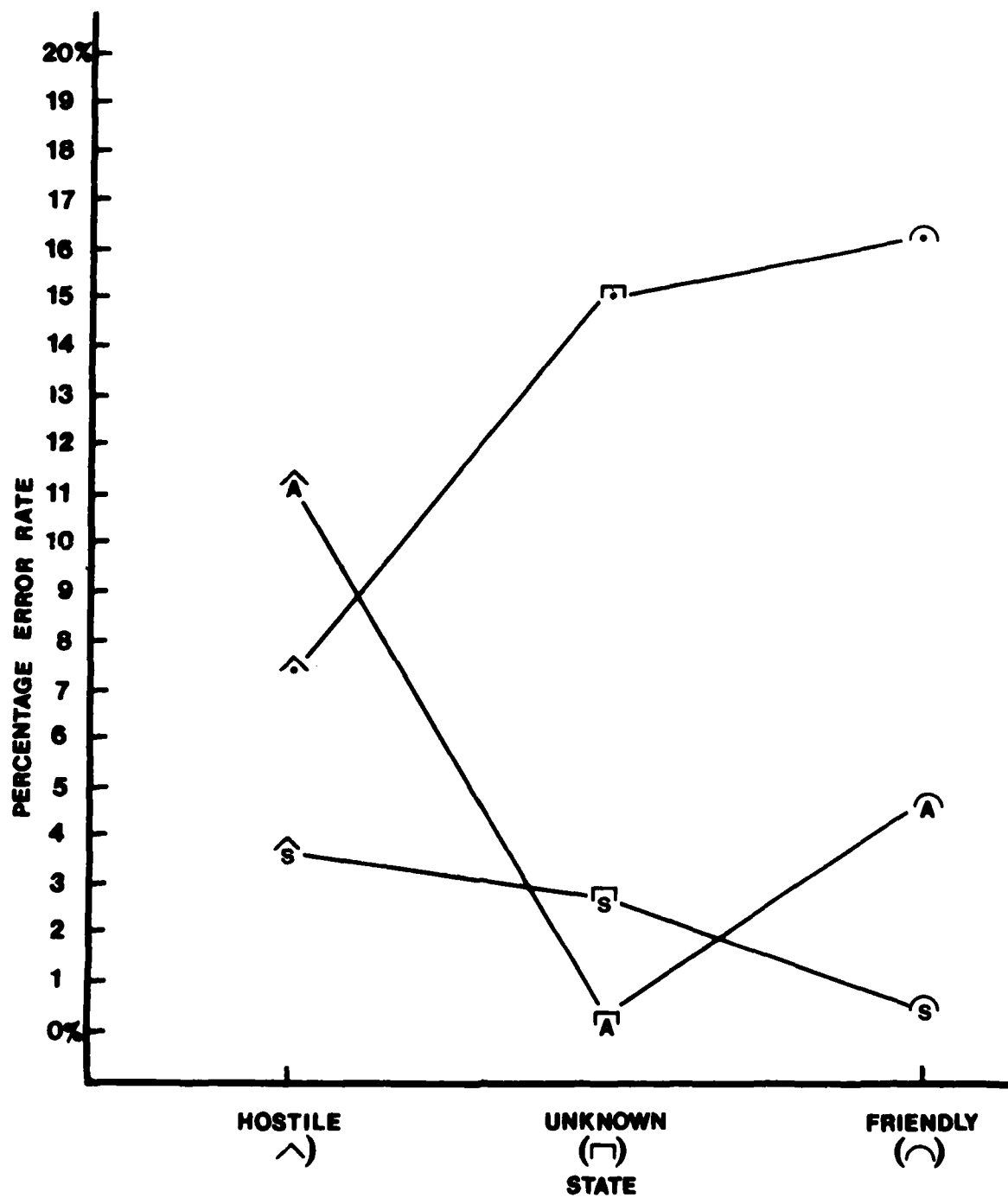
Figure 17.   Percentage of Errors for Each Symbol Combination
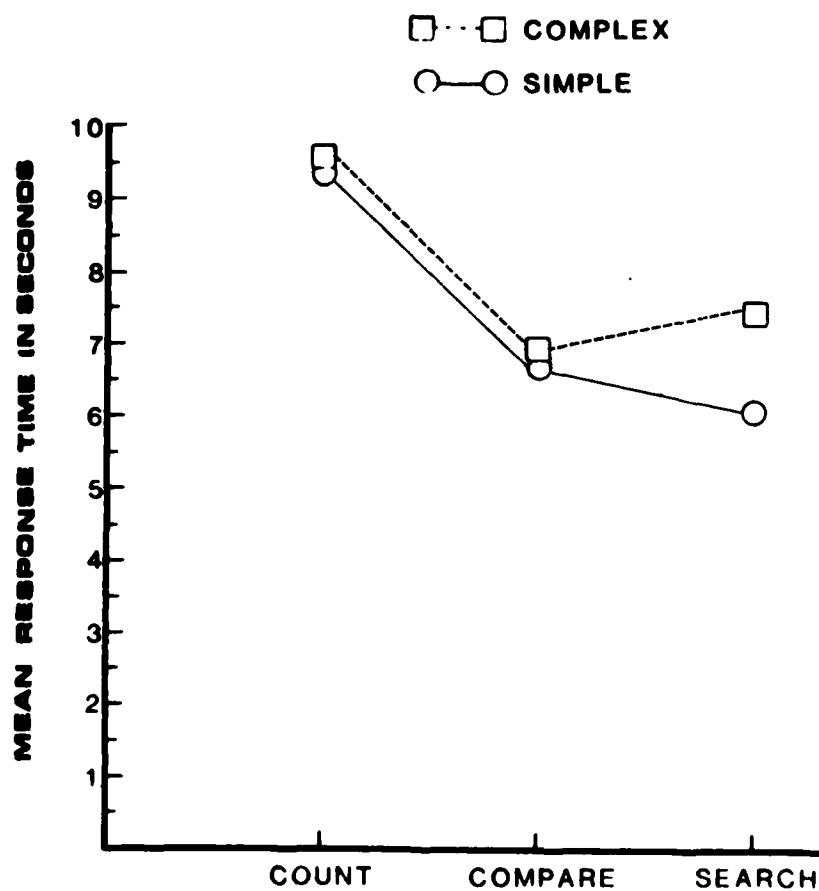
Figure 18.   Response Time as a Function of Question Type
and Question Complexity Level

Wilcoxin tests used to compare errors between complex and simple
questions for each question type, revealed a significant performance
difference on counting questions only, T (10) = 8.0, $p < 0.05$ (see
Figure 19). However, a problem format involving one of the simple count
questions makes any interpretation of this result highly speculative
(see subsection 1 of Section 5 and Figure 20).
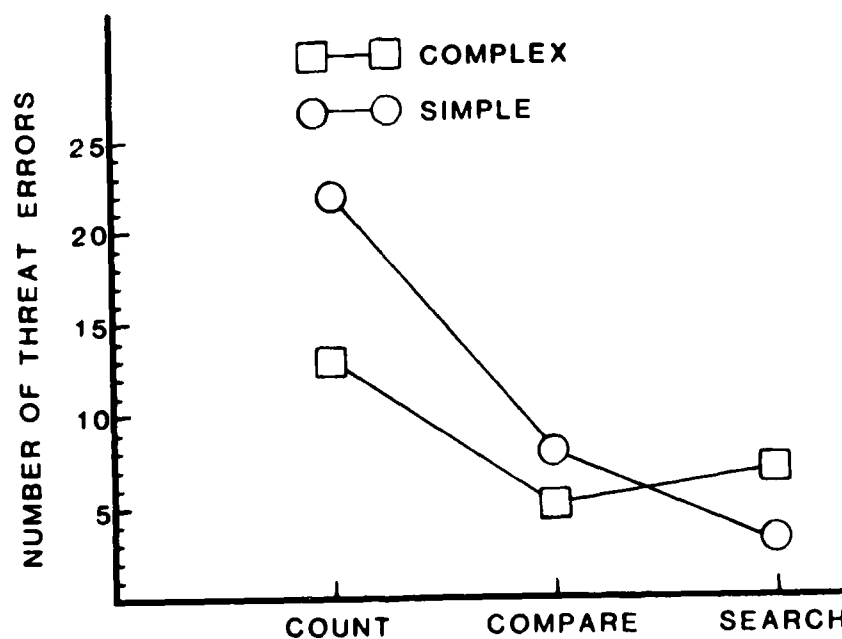
Figure 19. Number of Threat Errors for Each Question Type
by Question Complexity Level

SECTION V

DISCUSSION

The outline of this Section follows that of Section IV:

1) Effectiveness of redundant color-coding;

2) Effectiveness of the various symbol types and states; and

3) Performance differences as a function of question type and complexity.

Where appropriate, subjective data from the debriefing questionnaires will be presented and discussed.

1. EFFECTIVENESS OF REDUNDANT COLOR-CODING

In this particular application, the addition of redundant color-coding to shape-coded symbols was extremely successful in reducing operator response time. The overall average response time for a symbology question was reduced by forty percent through the additon of color-coding. In addition, the effectiveness of redundant color was more pronounced as the combat situation display became more complex; i.e., as the number of symbols on the display increased. Notice in Figure 14 how the response time with 10 achromatic symbols is almost identical to the response time with 30 color symbols. This reduction in seconds required to intepret and respond to a real-time situation display is critical to the pilot in the combat situation. Seconds may save his life and aircraft. In addition, the seconds saved allow him to spend more time "heads up" scanning the outside. This is vital when flying low-level at high speeds and attempting to outmaneuver enemy aircraft or jinking to avoid SAM or AAA fire.

The subjective data buttressed the objective data. On the final debriefing questionnaire, the pilots were asked, for each density level, how they felt the addition of color-coding affected their response time. At all three density levels, the overwhelming response was "decreased it a great deal" or "decreased it some" ($p < .01$ for each level). The

following comments were typical of others written in on the
questionnaires: "[black-and-white] as opposed to the color-coded ones
took more time"; "without color, ... becomes twice as difficult"; "the
more symbols the more color coding helped." On the final debriefing
questionnaire, they were also asked to rate how helpful such a display
would be in an actual combat mission. For the color-coding condition,
all respondents checked the display would have "helped a great deal" or
"helped some" $(p < .01)$. For the shape-coding condition, respondents
were pretty evenly split as to whether it would help or hinder. The
following comment states the ambivalence well: "Using black and white
with ten [symbols] helped some. More than ten would hinder."

The results of the error data, as shown in Figure 15, is a little
less straight-forward. There were significantly fewer errors with
color-coding at density level 30 $(p < 0.05)$, and, although not
significant, there were fewer errors at density level 20. One
intriguing feature of the data is the dramatic decrease in number of
errors in the color condition at density level 30. It is hypothesized
that what happened is that pilots changed their strategy with density
level 30 formats. Pilot comments on the debriefing questionnaires and
comments made to experimenters after the experiment suggested that when
both color- and shape-coding were available, the pilots used only the
color to determine state. (Typical comments were: "Just looked for
color then looked to see if SAM, aircraft, or AAA by symbol"; "Suggest
you drop [state] symbols when using color and use only basic symbols
such as A, S, and ●.) Looking at the number of errors at density levels
10 and 20 suggests this strategy might have been used. It is
hypothesized that with the density level 30 formats the pilots realized
that they would have to use both color- and shape-coding to pick out the
appropriate symbols because the formats were so complex. Therefore,
even though the response time increased, the error rate decreased because
they examined each symbol more carefully.

Another interesting twist to the error data was the unexpected
directional difference at density level 10. This can be attributed
primarily to one specific symbology question and its corresponding

format (see Figure 20). The question was a counting question: "How many unknown aircraft are there?" The correct answer was two. None of the subjects who received the question in the achromatic condition missed it. However, four subjects who received the question in the color condition, saw only one of the two unknown aircraft. Two of these four subjects later stated over the headset that they had overlooked the symbol in the upper part of quadrant one. Although the symbol was moving up toward the two lines of alphanumerics, it remained clearly visible on the screen for the duration of the task. This might suggest that when color was present, the shape of the hat was not attended to at first glance but noticed somewhat later. Because of the proximity of the yellow symbol to the white alphanumerics, the yellow symbol appeared lighter to the pilots and was considered part of the white alphanumerics. One pilot commented on the color-coding debriefing questionnaire that, "Yellow was a little difficult when it was close to the edge" [where the white alphanumeric scale readout appeared]. Since this particular format had a density level of 10, it tends to strengthen the earlier *hypothesis* that at density levels 10 and 20, color was scanned for first on the display.

a.   Results Related to Color-Coding Literature

These results confirm a number of findings in the current literature. First, redundant color with shape-coding decreases the amount of response time in search tasks (References 1, 3 and 5) and in identification tasks (References 2, 3, and 5). Thus, in displays where response time is of utmost importance, redundant color- and shape-coding has a high pay-off.

Additionally, color-coding appears most beneficial for displays which are unformatted, displays on which symbol density is high, and displays on which color coding is logically related to the operator's task (References 5 and 11).
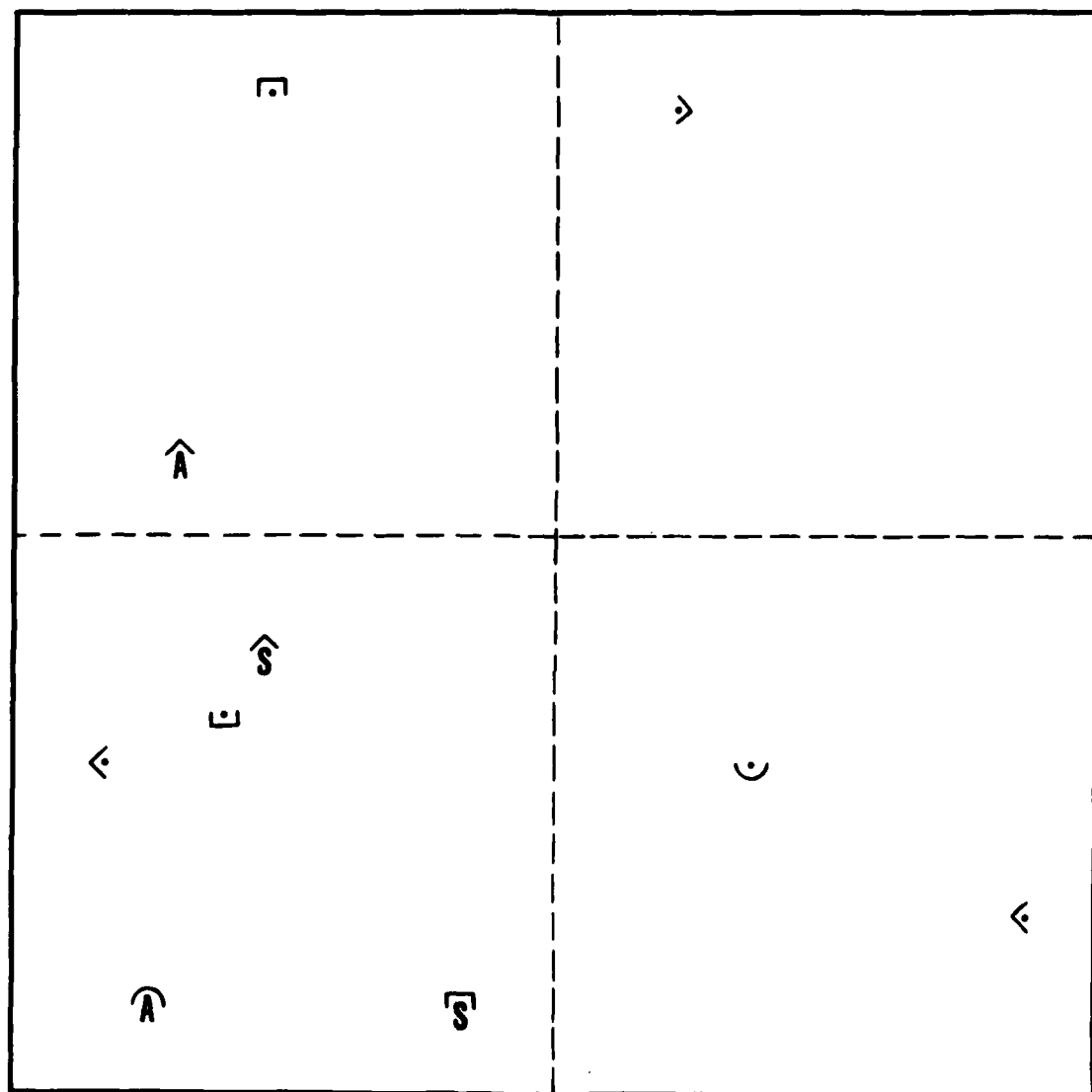
Figure 20.   Threat Display Format 1 (Density Level 10)

2. EFFECTIVENESS OF VARIOUS SYMBOL TYPES AND STATES

Two symbol type/state combinations required significantly longer times for identification than all other combinations: the /A̅\ and the /S̅\. Although the shape of these two symbol combinations is distinctly different, in both cases the top of the letter is approximately parallel with the hat-shaped designator. Thus, the similarity in hat-shaped designators to the letter shape and the fact that the designators were so close to the letters may have caused them to be more easily overlooked at first glance.

Another problem concerning the use of the /A̅\ symbol combination surfaced in the remarks sections of the debriefing questionnaires. Several pilots indicated that the /A̅\ symbol closely resembled a delta-shaped symbol (▲) that has occasionally been used in the past to denote an aircraft. This resemblance may have created confusion leading to a longer response time.

In additon to objecting to the use of the /A̅\ symbol combination, several pilots disliked the use of the symbol A for anti-aircraft artillery regardless of the state designator. They claimed to associate the symbol A with aircraft. One pilot suggested that to avoid this mistaken association, the symbol G (i.e., gun) be used for anti-aircraft artillery instead. Although this might give rise to a "parallelism" problem in the existing friendly state /G̅\, this would not be a problem if the ∧ and ∩ designators are changed as recommended in the succeeding paragraph.

Error rates among the symbol combinations could not be analyzed statistically because of unequal numbers of observations. However, the subjective data revealed the pilots did experience some difficulty in differentiating the state designators with the moving aircraft symbols (●). On the shape-coded debriefing questionnaire, a large number of the pilots checked they had difficulty differentiating between the ◈ and ⊙ symbol combinations in all four orientations: ◈ vs ⊙ (14 pilots); ◈> vs ⊙) (15); ◈ vs ⊙ (12); <◈ vs ⊙ (14). As one of the pilots

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commented on this questionnaire, "In black and white, the spear-shaped symbols and the half-moon shapes were difficult to distinguish." Based on this confusion factor between the $\wedge$ and $\cap$ designators, and the previously mentioned problems concerning the $\cancel{A}$ and $\widehat{S}$, it is suggested that new state designators be designed for the hostile and friendly states.

3.   PERFORMANCE DIFFERENCES AS A FUNCTION OF
      QUESTION COMPLEXITY AND TYPE

Two important concerns in the design of a real-time situation display symbology set are how much information can be conveyed by a particular symbol and how should that information be conveyed by a particular symbol.

In this study, complex questions required noting three encoded variables (type, state, and orientation) while simple questions required noting only two (type and state). The fact that the complex questions did not take significantly longer to respond to, and the fact that the complex questions did not have significantly greater error rates, suggests that encoding three variables was acceptable.

The significantly longer response time for counting questions may be accounted for by the fact that the pilot had to do an exhaustive scan of the whole display. For comparison questions he could zero in on two specific quadrants of the display, and for the search questions he had to scan only until he found the appropriate symbol. In interpreting the greater errors in counting questions, it must be kept in mind that four of those errors were related to the one problem question discussed earlier in subsection 1 of Section V. The pilots were asked on the shape-coding debriefing questionnaire to rate the difficulty of the three types of questions. The search questions were rated significantly easier than the other two $(p < 0.05)$.

Relating this back to the current literature, color has been shown to be the best coding method when search tasks were to be given, but numerals were found to be the best coding method for counting and comparing tasks (References 11 and 12).

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4. PILOT ACCEPTABILITY OF SYMBOL ORIENTATION TO DENOTE HEADING

The pilots were asked specifically in the shape-coding debriefing questionnaire to rate the adequacy of aircraft symbol orientation to denote heading. A significant number of them rated this convention as either good or excellent ($D = 0.489$, $p < 0.01$).

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

Based on the evaluation of the symbology set in this simulation study, the following conclusions and recommendations are made:

1.   Conclusion: Redundant color-coding for the shape-coded symbols on a situation display significantly reduces pilot response time.

Recommendation: Color displays and redundant color-coding should be used for any real-time combat situation symbology display installed in fighter aircraft.[1.]

Recommendation: Color displays and redundant color-coding should be incorporated for any display to be used by a highly-loaded operator in the performance of a series of complex tasks.

2.   Conclusion: The $\mathbb{A}$ proved to be a poor symbol choice in terms of slow response time and high percentage of errors.

Recommendation: The symbol for anti-aircraft artillery should be changed from A to G and tested in future simulations.

3.   Conclusion: Pilots took longer to respond to the $\mathbb{A}$ and $\mathbb{S}$ symbols, and in general found the $\wedge$ and $\cap$ state designators easily confused.

Recommendation: A new hostile ($\wedge$) state designator and friendly ($\cap$) state designator be designed and tested in future simulations.

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[1]NOTE: Current state-of-the-art technology has not produced a full-color cathode ray tube that does not wash out in high ambient light conditions found in the fighter cockpit. This technology should be given strong military research and development support in order that such technology will be available in time for implementation in the next generation fighter.

4.   Conclusion: Counting tasks took the pilots longer to complete, and they made more errors than on the other two types of tasks.

Recommendation: The use of subscripts to denote several of one symbol type rather than separate symbols be examined in future simulations.

5.   Conclusion: Pilots were receptive to the idea of using aircraft symbol orientation to denote aircraft heading.

Recommendation: The convention of using aircraft symbol orientation to denote aircraft heading for all twelve clock positions be tested in future simulations.

Recommendation: The simulation incorporate changes of aircraft heading so that symbol rotation effects can be measured.

6.   Conclusion: This evaluation relied heavily on the subjective debriefing questionnaire data to interpret the objective findings.

Recommendation: Any studies of symbology sets to be used by highly-loaded operators performing complex series of tasks should be evaluated in a simulated environment, and subjective operator data should be used in the interpretation of the objective data.

APPENDIX A

COCKPIT SIMULATOR

1. ELECTRO-OPTICAL FORMATS

Four electro-optical formats were used in the present study to
provide information for utilization by the pilot (see Figure 2). The
following describes each display in detail:

a. Head Up Display (HUD) (see Figure 3)

The HUD supplied flight information in symbolic form on a
combiner glass in the pilot's forward field of view. The horizon and
flight path angle lines of the flight path scale represented the horizon
and each five degrees of flight path angle (FPA) between plus and minus
90 degrees. Positive FPA was presented as solid lines and appeared
above the horizon line. Negative FPA was presented as dashed lines and
appeared below the horizon line. The five degree increments were
numbered on either end of the FPA lines. A minus sign preceded the
numbers for negative angles.

The aircraft velocity vector was represented by a flight path
marker (FPM) which denoted the point toward which the aircraft was flying
at all times. The FPM moved horizontally and vertically, but was not
roll stabilized to show bank angle. Rather, the flight path scales and
their associated numbers were roll-stabilized and rotated to the
appropriate bank angle.

The airspeed, heading, and altitude scales were not roll-
stabilized. The airspeed and altitude scales were vertical and appeared
on the left and right sides of the display, respectively. The heading
scale was horizontal and appeared at the top of the display. The
airspeed scale was graduated in 25 knot increments and numbered each 50
knots. At least three sets of numbers were visible at all times. An
exact readout of current airspeed was presented in the window in the

center of the scale. The readout changed whenever the airspeed changed by one knot. When any digit changed faster than two times/second, that digit was displayed as zero. The scale moved continuously. The scale numerics were not superimposed over the window, but in that area were removed from the CRT by software blanking. The abbreviation TAS for true airspeed appeared below the airspeed scale in the CRUISE segment. The current UHF radio frequency was displayed below the airspeed scale.

Barometric altitude was displayed on the altitude scale on the right side of the HUD. The scale was graduated in 250-foot increments numbered each 500 feet. At least three sets of numbers were visible at all times. The total range of the altitude scale was from minus 1,000 feet to plus 99,999 feet with 1,500 feet in view at all times. An exact readout of the altitude was provided in the window in the center of the scale. The readout changed whenever the altitude changed by one foot. The scale moved continuously. The scale numerics were not superimposed over the window, but were removed from the CRT by software blanking in that area. When a 500-foot scale mark moved off the scale, the numerics were removed at that end. Numerical digits were added to the scale when a 500-foot mark was added to the scale as it moved. When any digit changed faster than two times/second, that digit was displayed as zero. An abbreviation designating the current flight segment appeared below the altitude scale. The abbreviation CRUS was displayed during the CRUISE flight segment.

The heading scale was displayed at the top of the HUD. Forty scale degrees were in view at all times, graduated in five degree increments. Every other increment was labeled by a two digit number above it. Total heading scale range was 360 degrees. The aircraft magnetic heading was displayed to the nearest degree in the window. The scale moved continuously. When a ten degree mark moved out of the field-of-view, two digits were removed at that end. Two digits were added to the scale when a ten degree mark was added to the scale. The scale numerics were not superimposed over the window, but were removed from the CRT by software blanking in that area.

The flight director symbol indicated horizontal and vertical steering error information with respect to the flight path marker. The X and Y commands to position the flight director symbol were such that the pilot flew the flight path marker to the flight director by steering the aircraft in pitch and/or bank angle, i.e., the flight director was moved by the software to the flight path marker when the proper control signals were received.

The vertical velocity was displayed above the altitude scale in digital form with the readout changing in one foot per minute increments over a range of 0 to 9,999 feet per minute. A caret indicated vertical velocity direction, i.e., up or down. As in the altitude scale, when any digit on the format changed faster than two times per second that digit was displayed as zero.

b. Horizontal Situation Format (HSF) (see Figure 4)

A seven-inch diagonal color monitor was used to present simplified navigation information in a track-up format. A map representing a combat environment 80 nautical miles in length was used. The aircraft symbol was fixed in the center of the display. The aircraft track was displayed at a fixed location centered at the top of the HSF. The value displayed ranged from 0 to 359 degrees. The track to the next succeeding waypoint was displayed in the lower left corner as indicated in the figure with a N preceding the numerical value of the track. The map scale was displayed in the lower left corner of the HSF just below the track of the next waypoint. This scale indicated the range covered by the map in nautical miles measured vertically. The fuel quantity was displayed in a fixed location to the right of the range scale in the lower portion of the HSF. Fuel quantity was displayed with an F preceding the digital readout of the remaining fuel in pounds, e.g., F 17500.

The waypoint symbol and its identification (ID) were displayed anytime that waypoint was on the map. Each waypoint had an ID, which was its numerical designation. Information concerning the next waypoint, its distance from the aircraft, and the time required to reach it was displayed in the upper left portion of the HSF. The waypoint identifier was given, followed by the distance in nautical miles and the time to go to the nearest tenth of a minute.

The distance and time to the next target (along the planned route) were displayed in the upper right portion of the HSF. Again the target identifier was given, followed by the distance in nautical miles, and the time to go to the nearest tenth of a minute. The track, distance, and time required to fly directly to the next target were displayed in the lower right position of the HSF under abbreviations DIR TO TGT.

The groundspeed was displayed above the time to the next target. Display of groundspeed was to the nearest knot and was preceded by the alphabetical characters GS, e.g., GS 461.

The crosstrack deviation was displayed on the HSF by the relative displacement of the map track line from the aircraft symbol. The aircraft was positioned in the center of the display and the map moved under the aircraft symbol and was positioned to show the actual aircraft position in relation to the desired track.

The symbology formats were overridden by the aircraft symbol, its groundtrack, and the areas at the top and bottom of the display dedicated for alphanumerics.

c.   Multifunction Keyboard (MFK) (see Figures 6 and 11)

Each MFK task event consisted of either one task or several subtasks. A subtask is defined as a set of MFK and DEK selections which could be considered a complete task if accomplished independently. The only MFK task event given in this study that consisted of two or more subtasks was the IFF mode/code change. The pilot had to accomplish both

a mode change and a code change in order to complete one task event. The pilot was allowed to accomplish either the mode change or code change first.

Due to computer memory limitations and time constraints, only the options required for the tasks to be used in this experiment were programmed. If the pilot selected an option that was not programmed, he received the message OPTION N/A for that switch on the CRT. The legend disappeared with the selection of a programmed option. Within the CRUISE segment, mistakes made by pushing an inappropriate programmed switch were also corrected by selecting the correct option.

Once the pilot had progressed to the switch action that activated the DEK (DEK illuminated), each digit selected was displayed to the pilot on the keyboard CRT. When the pilot selected the last digit (defined by the type of task), the preentry readout provided the pilot with the capability to verify that the digits selected were accurate. If the pilot made an error that was in the appropriate range or realistic for the task (example: 236.7 instead of 236.6 UHF as the frequency), the incorrect digit(s) were displayed in the pre-entry readout (236.7). In order to correct the mistake, the pilot had to clear the incorrect digit(s). One push of the CLEAR key on the DEK erased the last selected digit. Two pushes of the CLEAR key erased all the digits selected since the last activation of the ENTER key. The DEK remained activated and lighted after any push of the CLEAR key.

In addition to the pre-entry readout, an error message was displayed to the pilot when an error was made that was out of the appropriate range or unrealistic for a task. For example, if 9 was selected for the first IFF code digit for mode 3, the message BAD DATA was displayed to the pilot next to the pre-entry readout since the first digit could be no larger than 7. The actual illegal digit never appeared on the pre-entry readout, but was ignored by the computer. The DEK remained active and when the pilot made a legal switch hit on the DEK, the BAD DATA message disappeared. A second example involves a pilot who had selected 69 as the first two digits of a IFF code (6600) instead

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of 66. In this case the first digit was legal, but the second digit was out of the appropriate IFF range. Since the computer ignored the illegal digit and the first digit selected was legal, the pre-entry readout was 6 with the BAD DATA message also displayed. Of the first two digits, only the second digit had to be reselected.

In the case where the pilot has pushed too many legal digits, the message CHECK DATA was displayed next to the pre-entry readout, the pre-entry readout remained except that the surplus digits were automatically ignored by the computer, and the DEK remained active. If the remaining selected digits were the desired entry (6600 for the mode 3 code), the pilot pushed the ENTER key. If the desired entry was 6606 instead of 6600, however, the pilot had to operate the CLEAR function to erase the 6 and select 0 in order to complete the task event correctly. The CHECK DATA message disappeared with the first hit of the CLEAR or ENTER key.

Once a task or subtask was completed, whether it was correct or incorrect, all recording of data stopped. If a data entry had been required as part of the task, the DEK deactivated and the pre-entry readout disappeared. The computer then checked to see if the data selections and entry were the same as the information programmed for the subtask. The following describes the MFK configuration and operating procedures after the computer determined whether the completed task or subtask was incorrect or correct.

(1) Incorrect Task or Subtask Completion

If a task or subtask was completed incorrectly, the pilot was required to redo it. In the case of the IFF mode/code change, the pilot only had to redo the subtask that had an error. The subtask or task error was displayed to the experimenters on the experimenters' console and the pilot's MFK became inoperable. Note that the DEK was deactivated; if the pilot had to make a digit entry to correctly complete the retry, he had to reselect the switch on the MFK which calls up the DEK. After the pilot was notified by Experimenter #2 that an error was made and the pilot responded that he understood, Experimenter #1 selected

the KEYBOARD UNLOCK switch to restore the MFK. The pilot then started to redo the task or subtask; the pilot's first switch hit on the MFK of the retry initiated the recording of data. When the keyboard operation was completed again, the recording stopped and the computer verified the entry.

(2) Correct Subtask or Task Completion

When the computer verified that a completed subtask or task was correct, the computer then checked whether more subtasks were to be completed at that time. If another subtask was to be completed, the MFK remained activated at the last level used during the completion of the previous subtask. (The DEK was automatically deactivated at subtask completion whether correct or incorrect.) The pilot's first switch hit on the MFK for the next subtask initiated data recording. In the case where no more subtasks were to be completed, the MFK became inoperable and the DEK became deactivated and the task was considered finished.

An exception where the pre-entry readout terminal readout remained after subtask completion was when the pilot entered too few legal digits (example: 236 for 236.7 UFH frequency). In addition, the MFK and DEK remained active and the message RE-ENTER DATA was displayed next to the readout. The pilot's first MFK or DEK switch hit of the retry initiated the recording of data and erased the message.

d. Status Format (SF) (see Figure 5)

A six-inch diagonal black-and-white monitor was used to display mission-related status information to the pilot. In the CRUISE segment, the SF displayed communications and navigation data.

2. DEDICATED DISPLAYS AND CONTROLS

Most of the backup flight instruments in the cockpit simulator were inoperable so that the pilot was forced to use the information displayed on the HUD and HSF to maintain control of the cockpit simulator. However, the following instruments, switches and indicators were operable and available for use by the pilot during testing:

a)   Angle of Attack (AOA). The AOA indicator operated through a range from 0 through 30 units.

b)   HUD Declutter Switch. A three-position switch on the HUD control panel was implemented by which the pilot could select the amount of information to be presented on the HUD. In all three switch positions, the horizon, ladder, flight director, flight path marker, and weapons symbology were presented on the HUD. In one of the positions, only the aforementioned symbology was presented. In a second position, exact readouts of the altitude, airspeed, heading and weapon option also appeared. In the third position, the HUD presented altitude, airspeed, and heading scales as well.

c)   Master Arm Switch. Had to be in the arm position in order to deliver weapons.

d)   Stick Switches. Trim button adjusted stick to neutral position. Bomb release button enabled a selected weapon option to be released.

Engine instruments provided were:

e)   RPM. Indicated engine speed in percent RPM. The instrument was calibrated from 0 - 100%. The normal operating range was 52 - 100%.

f)   Turbine Outlet Pressure (TOP). TOP was used as an indication of engine performance. Calibrated in inches of mercury, the operating range was 25 - 45 in. Hg.

g)   Turbine Outlet Temperature (TOT). Indicated TOT in degrees C (pointer and digital readout). The usable range was 0 - 1000 degrees C.

h)   Oil Pressure. Indicated engine oil system pressure in psi. The instrument was calibrated 0 - 60 psi with a normal operating range of 27 - 53 psi.

APPENDIX B

SITUATION DISPLAY FORMATS

As mentioned in subsection 1b of Section II, a total of 27 formats were developed. An example of one of the formats from each of the three density levels (10, 20, and 30) symbols is shown in Figures B1, B2, and B3. Each pilot was asked one question about each format in the achromatic shape-coded condition, and one about it in the redundant color- and shape-coded condition. However, given the experimental design, this meant that he would see each format once in the morning and again in the afternoon several hours later. Thus, there was very little chance of his recalling the format.

AFWAL-TR-82-3080
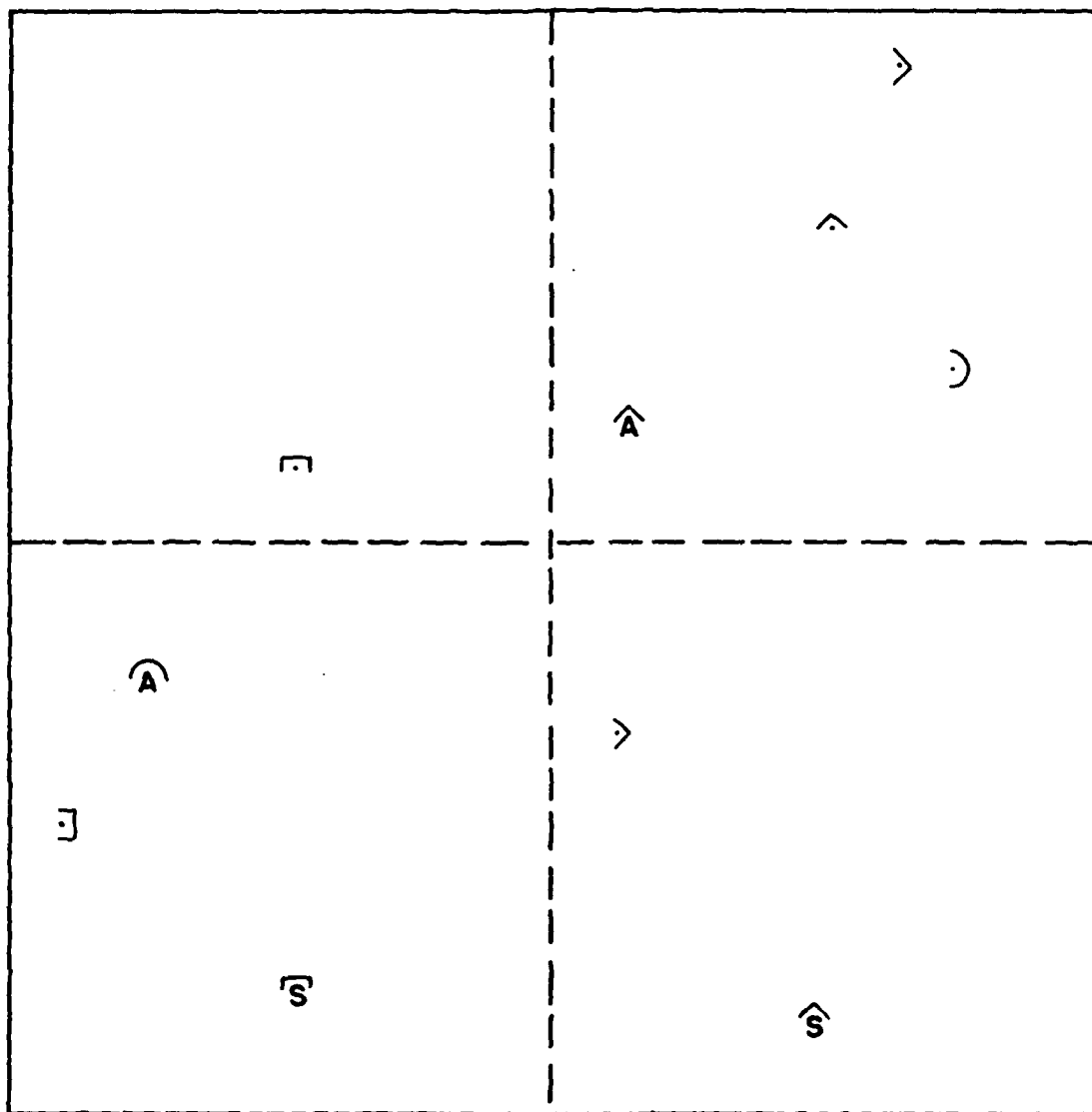
Figure B1. Combat Situation Format, Density Level 10 Example

60
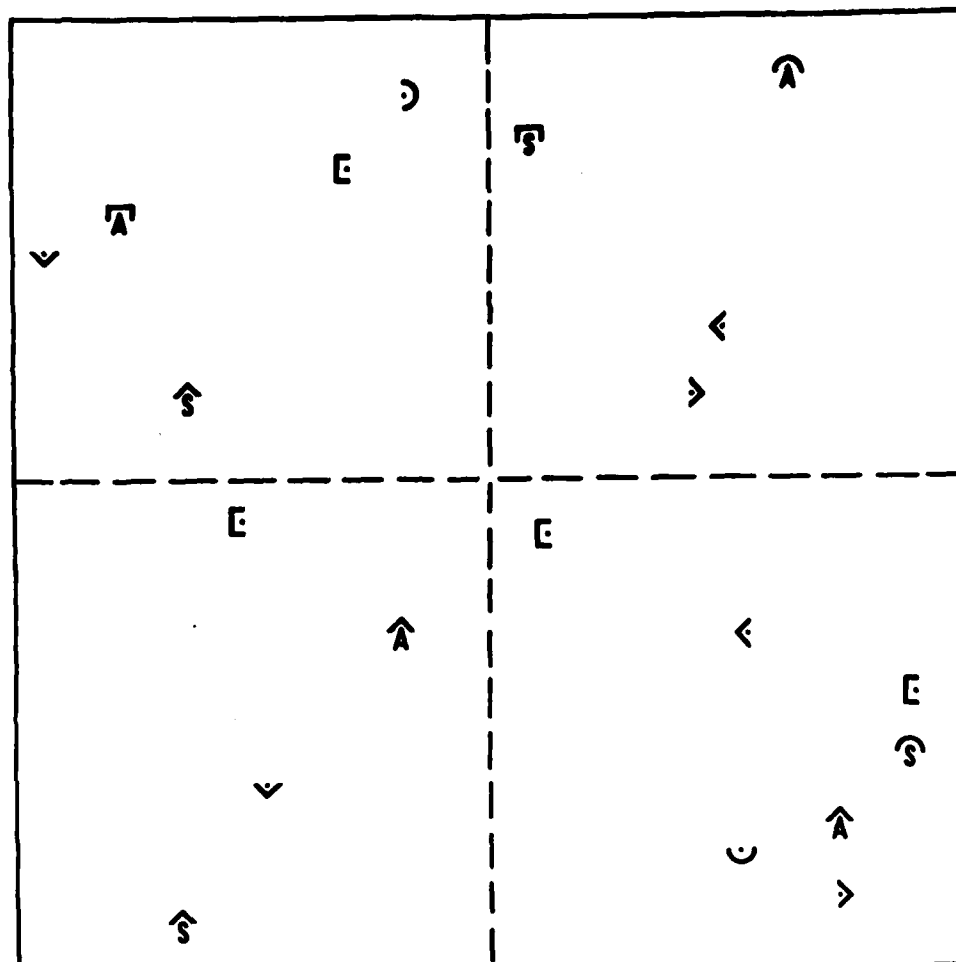
Figure B2. Combat Situation Format, Density Level 20 Example
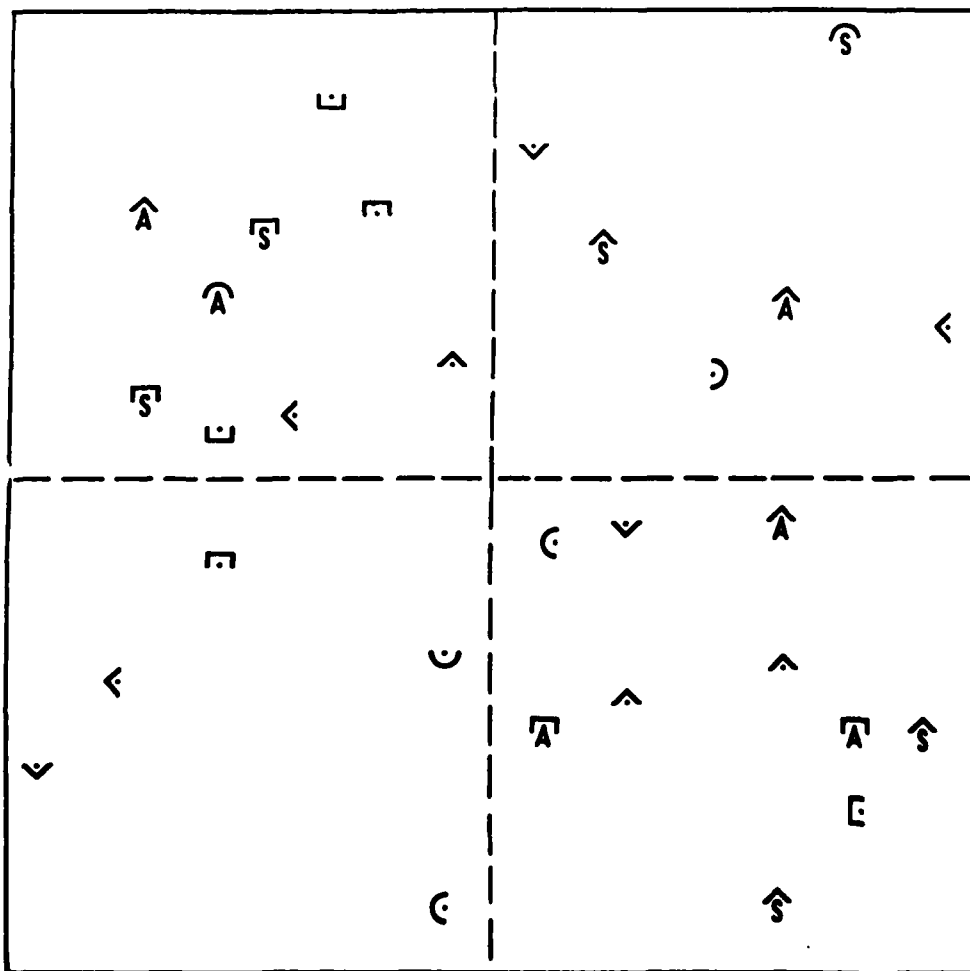
Figure B3. Combat Situation Format, Density Level 30 Example

APPENDIX C

EXPERIMENTERS' CONSOLE AND SIMULATOR FACILITIES

1.   EXPERIMENTERS' CONSOLE

The console was equipped with CRT displays and status light
matrices which provided the experimenters with the capability of
monitoring the displays in the simulator and the actual switch actions.
A layout of the experimenters' console is shown in Figure C1. The
following list specifies the functions allocated to each piece of
equipment on the console. Each letter refers to the notations used on
the layout.

A = Experimenters' status display (Figure 9); presented flight and
task event information

B = Repeater display of the multifunction switch legends on the MFK

C = Repeater display of the SF

D = Repeater display of the HUD

E = A second repeater display of the SF

F = Repeater display of the HSF

G = Status panel lights (Each status light stayed lit as long as
the corresponding switch in the cockpit was activated.)

H = Master power switch for facility

I = Abort switch for McFadden flight control systems

J = Interphone options (Note: the pilot's mike was always hot)

K = On/off switch for interphone system

L = Switch enabled communication between Experimenters #1 and #2

M = Switch enabled Experimenters #1 and #2 to communicate with
pilot

N = Switch enabled communication between all three experimenters
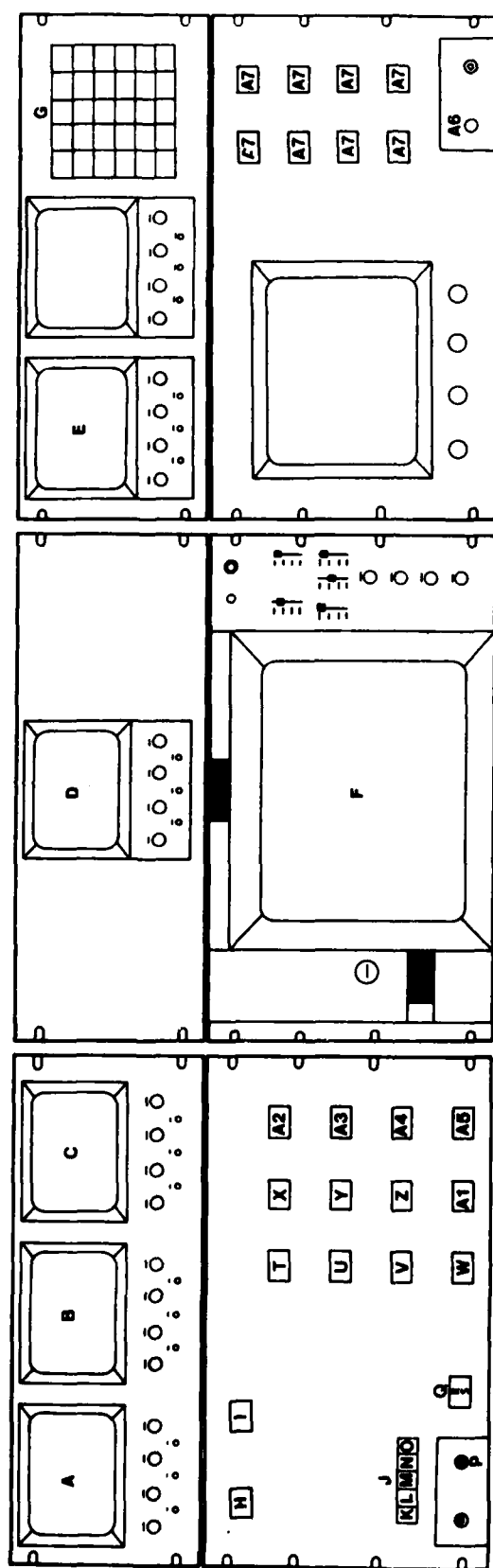
Figure C1. Layout of the Experimenters' Console

O = Switch enabled communication between all three experimenters and the pilot

P = Volume control for Experimenter #1's headset

Q = Voice recorder options

R = Pause switch for voice recorder

S = Run switch for voice recorder

T = Reset switch for McFadden system

U = Pre-event switch; activation initiated thirty seconds of flight data recording

V = Event marker switch; activation started recording of flight data and task event data, started console timer, and either unlocked MFK or displayed new symbol set

W = Mission complete switch (guarded); activation initiated the computerized data reduction procedures

X = Run switch for simulation

Y = Track advance; used after the last symbology task in the CRUISE segment to advance to the CCIP AUTO segment

Z = Keyboard unlock switch; activation unlocked MFK in those task events where recording terminated after the pilot entered incorrect legal digits

A1 = Indicated whether tape recording was continual or voice activated

A2 = Hold switch for simulation

A3 = Emergency 1 switch (Originally intended as a means of preventing programmed emergency conditions from occurring as scheduled. Not used in this experiment.)

A4 = Segment complete switch (guarded); activation terminated test segment and automatically updated the controls/displays configuration to that specified by the next higher matrix number. The automatic sequencing could be overridden via input on the terminal. (Not used in this experiment.)

A5 = Task abort switch (guarded); activation terminated recording of task event data and initialized system for next task event

A6 = Volume control for Experimenter #2 headset.

A7 = Hardware configuration switches; the switches indicated which set of function select switches or multifunction switches were activated (front left panel or left console) and which DEK was activated (left or right console) (Not used in this experiment).

2. SIMULATION FACILITIES

The simulator consisted of interconnected facilities as shown in Figure B2. A functional description of each system element is provided below.

a. PDP 11/50

Configuration Control - used to set up the cockpit controls/displays configuration prior to each flight.

Display Assembly - generated image lists to be further processed by the Ramtek raster symbol generator. Data from the simulation models was used for the HUD, HSF, and SF formats.

Map Driver - provided output control of map data to the Ramtek symbol generator.

Keyboard Logic - processed incoming switch data and determined the display state of all the keyboards.

Flight Control Sampling and Scaling - buffered and scaled flight control data to be used by simulation models.

Simulation Models - provided all necessary aircraft parameters to be used in display processing.

Data Recording - recorded cockpit display parameter data on magnetic tape.

Data Reduction - an off-line program reduced the raw real-time recorded data into meaningful data that could be analyzed.

b. Ramtek

Display Generation - processed image lists to display HUD, HSF, and SF.

c. Cockpit

Keyboard Input/Output - provided a switch image buffer of all cockpit switch states to be sampled by the PDP 11/50. Also decoded keyboard display data being set from the PDP 11/50.

Flight Control - Digitized analog stick, rudder, and thrust control inputs and buffered the resultant data for transmission to the PDP 11/50.

d. Support Equipment

Console Terminal - system operators input/output device to the PDP 11/50.

Printer and Card Reader - hard copy input/output to the PDP 11/50.

Disk Drive - mass storage device for the operating system.

Magnetic Tape Drive - mass storage device for data collection.

Discrete and Analog Input/Output - input/output port from the PDP 11/50 to all cockpit and experimenter consoles' subsystems.

APPENDIX D

DAILY TEST SCHEDULE

The daily test schedule (Table D1) indicates the approximate time and type of activity to train, test, and debrief one pilot during one day of the experiment. Times for controls/displays familiarization, training missions, test missions, data verification, and debriefing are indicated in the schedule provided. As was mentioned in Section III, each pilot participated in a three hour briefing at his home base prior to the on-site testing.

TABLE D1

DAILY TEST SCHEDULE

APPROXIMATE TIMES	ACTIVITY*
0830 - 0930	Cockpit Briefing
0930 - 0945	Break
0945 - 1005	Training Mission for Coding Condition I
1005 - 1010	Break
1010 - 1040	Data Mission 1
1040 - 1055	Break
1055 - 1125	Data Mission 2
1125 - 1155	Debriefing Questionnaire for Coding Condition I
1155 - 1300	Lunch
1300 - 1320	Training Mission for Coding Condition II
1320 - 1325	Break
1325 - 1355	Data Mission 3
1355 - 1410	Break
1410 - 1440	Data Mission 4
1440 - 1510	Debriefing Questionnaire for Coding Condition II
1510 - 1550	Final Debriefing Questionnaire

*See Section III **Test Procedure**.

APPENDIX E

INITIAL CONDITIONS AND COMMANDED FLIGHTPATH
FOR DATA MISSION ONE

-    This experiment conducted four training missions and four data missions. initial conditions and commanded flightpath information for Data Mission One are detailed below.

The cockpit was in the following configuration at the initialization of each flight:

a)   Flight mode switches - CRUISE flight mode switch activated.

b)   HUD - CRUISE mode symbology appeared (see Figure 3). A true airspeed (TAS) of 350 knots, and an altitude of 1228 feet was shown.

c)   HSF - CRUISE mode symbology appeared (see Figure 4). The aircraft was located in the center, groundtrack up, with a situation format of 30 symbols around it. No symbology questions were asked about this first situation format.

d)   SF - CRUISE mode symbology, consisting of communication and status information appeared (see Figure 5).

e)   MFK - The MFK Tailored page appeared (see Figure 6). However, the MFK was inoperative until Experimenter #1 unlocked it from the experimenters' console.

AFWAL-TR-82-3080

TABLE E1

INITIAL CONDITIONS FOR EACH SEGMENT OF DATA MISSION ONE

SEGMENT	UHF	TACAN	IFF	ALT SET	WPN OPT 1	WPN OPT 2	WPN OPT 3	WPN OPT 4	FLY TO
CRUISE	Pres. 337.8 Prev. 236.6	Pres. 107X Prev. 126X	Normal Mode 1:21 Mode 2:0111 Mode 3:1400 Mode 3 OUT	28.99	18 MK 82 PR ALL 75FT NT	10 MK 82 PR ALL 90FT NT	14 MK 82 SNGL 90FT N	16 MK 82 PR ALL 50FT NT	7
CCIP AUTO	Pres. 348.0 Prev. 337.8	Pres. 115X Prev. 107X	Normal Mode 1:21 Mode 2:0111 Mode 3:2100 ALL MODES IN	28.99	18 MK 82 PR ALL 75FT NT	10 MK 82 PR ALL 90FT NT	14 MK 82 SNGL 90FT N	16 MK 82 PR ALL 50FT NT	9

APPENDIX E

INITIAL CONDITIONS AND COMMANDED FLIGHTPATH
FOR DATA MISSION ONE

·   This experiment conducted four training missions and four data missions. initial conditions and commanded flightpath information for Data Mission One are detailed below.

The cockpit was in the following configuration at the initialization of each flight:

a)   Flight mode switches - CRUISE flight mode switch activated.

b)   HUD - CRUISE mode symbology appeared (see Figure 3). A true airspeed (TAS) of 350 knots, and an altitude of 1228 feet was shown.

c)   HSF - CRUISE mode symbology appeared (see Figure 4). The aircraft was located in the center, groundtrack up, with a situation format of 30 symbols around it. No symbology questions were asked about this first situation format.

d)   SF - CRUISE mode symbology, consisting of communication and status information appeared (see Figure 5).

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CCIP AUTO	Pres. 348.0 Prev. 337.8	Pres. 115X Prev. 107X	Normal Mode 1:21 Mode 2:0111 Mode 3:2100 ALL MODES IN	28.99	18 MK 82 PR ALL 75FT NT	10 MK 82 PR ALL 90FT NT	14 MK 82 SNGL 90FT N	16 MK 82 PR ALL 50FT NT	9

Figure E1. Commanded Flight Path for Data Mission One

APPENDIX F
MISSION ONE SCRIPT

Bracketed material [ ] is explanatory information not read by Experimenter #2. "Dragon 10" is the pilot's call sign. Note how at the conclusion of each task (second line of each task narrative), Experimenter #2 acknowledges the pilot's symbology question answer or his completion of a MFK task. The first two lines of the script are to establish that the headsets are operational.

DRAGON _10_, THIS IS FRANKFURT CONTROL, SQUAWK IDENT.

DRAGON _10_, I HAVE RADAR CONTACT, CONTINUE ON COURSE.

[PRE-EVENT]

[TASK 1 SYMBOLOGY]

DRAGON _10_, DOES QUADRANT 3 OR QUADRANT 4 HAVE THE MOST UNKNOWN AIRCRAFT?

DRAGON _10_, ROGER.

[PRE-EVENT]

[TASK 2 SYMBOLOGY]

DRAGON _10_, HOW MANY ENEMY AIRCRAFT ARE HEADING TOWARD 9 O'CLOCK?

DRAGON _10_, ROGER.

[PRE-EVENT]

[TASK 3 UHF CHANNEL CHG]

DRAGON _10_, CONTACT ME NOW ON INDIA FREQUENCY.

DRAGON _10_, YOU'RE LOUD AND CLEAR, HOW ME?

DRAGON _10_, ROGER.

[PRE-EVENT]

[TASK 4 SYMBOLOGY]

DRAGON   <u>10</u>,   DOES QUADRANT 1 OR QUADRANT 4 HAVE THE MOST ENEMY AIRCRAFT HEADING TOWARD 12 O'CLOCK?

DRAGON   <u>10</u>,   ROGER.

[PRE-EVENT]

[TASK 5 SYMBOLOGY]

DRAGON   <u>10</u>,   HOW MANY UNKNOWN AAA SITES ARE THERE?

DRAGON   <u>10</u>,   ROGER.

[PRE-EVENT]

[TASK 6 SYMBOLOGY]

DRAGON   <u>10</u>,   WHICH QUADRANT HAS ALL OF THE UNKNOWN AIRCRAFT HEADING TOWARD 12 O'CLOCK?

DRAGON   <u>10</u>,   ROGER.

[PRE-EVENT]

[TASK 7 IFF MODE CHG, IFF IN/OUT]

DRAGON   <u>10</u>,   SQUAWK MODE 3 IN AND SET MODE 3 CODE TO VICTOR.

DRAGON   <u>10</u>,   READ YOUR SQUAWK 5 BY.

[PRE-EVENT]

[TASK 8 SYMBOLOGY]

DRAGON   <u>10</u>,   WHICH QUADRANT HAS THE ENEMY AAA?

DRAGON   <u>10</u>,   ROGER, TRAFFIC AT 10 O'CLOCK, CROSSING RIGHT TO LEFT.

[PRE-EVENT]

[TASK 9 IFF MODE CHG]

DRAGON   10 ,   CHANGE YOUR MODE 3 SQUAWK TO XRAY.

DRAGON   10 ,   I READ YOUR SQUAWK.

[PRE-EVENT]

[TASK 10 TACAN CHANNEL CHG]

DRAGON   10 ,   TUNE MANSHACH TACAN, NOVEMBER 3.

DRAGON   10 ,   ROGER, ARE YOU ON TOP?

[PRE-EVENT]

[TASK 11 SYMBOLOGY]

DRAGON   10 ,   DOES QUADRANT 1 OR QUADRANT 4 HAVE MORE

                              ENEMY AIRCRAFT HEADING TOWARD 6 O'CLOCK?

DRAGON   10 ,   ROGER, WHAT'S YOUR ALTITUDE?

[PRE-EVENT]

[TASK 12 FLY TO WAYPT NO]

DRAGON   10 ,   YOU ARE CLEARED FROM YOUR PRESENT POSI-

                              TION TO NOVEMBER 12.

DRAGON   10 ,   YOU HAVE TRAFFIC AT 12 O'CLOCK LOW, FAST-

                              MOVER.

[PRE-EVENT]

[TASK 13 SYMBOLOGY]

DRAGON   10 ,   WHICH   QUADRANT   HAS   THE   UNKNOWN   SAMS?

DRAGON   10 ,   ROGER, CONTINUE.

[PRE-EVENT]

[TASK 14 SYMBOLOGY]

    DRAGON   10 ,   HOW MANY ENEMY ARICRAFT ARE HEADING

                                      TOWARD 12 O'CLOCK?

    DRAGON   10 ,   ROGER.

[TRACK ADVANCE HIT]

[PRE-EVENT]

[TASK 15 WPN OPT SELECTION]

    DRAGON   10 ,   SELECT WEAPON OPTION 2. CLEARED FOR DROP.

1-6

PILOT'S FLIGHT PLAN AND FLIGHT LOG

ARTC FREQ	A 28.98	E 10	I 348.0	S 267.6	X 2100
	B 30.24	F 17	J 390.9	U 6500	Y 2700
	C 29.92	G 19	K 262.5	V 3700	Z 1097/254

AIRCRAFT IDENT	TAKE-OFF TIME	TOTAL DISTANCE	TOTAL ETE		TOTAL AMT FUEL
DRAGON 10		241	41.2		

495500N 063300E	IDENT FREQ	MAG CRS	DISTANCE REMAIN	GROUND SPEED	ETE REMAIN	ETA ATA	LEG REMAIN	ACTUAL FUEL REMAIN
500838N		$^07_2$	44	$^35_0$	7.5			
071484E			197		33.7			
502220N		$^08_0$	79	$^35_0$	13.5			
083248E			118		20.2			
503826N		$^07_4$	57	$^35_0$	9.7			
092706E			61		10.5			
503399N		$^07_5$	61	$^35_0$	10.5			
102589E			—		—			

OPTION 1	OPTION 2	OPTION 3	OPTION 4
18MK82 PR ALL 75FT NT	10MK82 PR ALL 90FT NT	14MK82 SNGL 90FT N	16MK82 PR ALL 50FT NT

NOVEMBER DATA

1	SPA 116Y	5	481950N 114308E	9	4	13	2
2	KOB 125Y	6	484975N 123390E	10	5	14	3
3	MAN 115X	7	494800N 131089E	11	8	15	6
4	LE1 110X	8	502175N 132500E	12	9	16	7

Figure G1. Modified Flight Plan (AF Form 70) for Data Mission One

APPENDIX H

DEBRIEFING QUESTIONNAIRES AND RESULTS

Immediately after each symbol coding condition was evaluated (two data flights), the pilot was given a questionnaire concerning the symbology set and its coding condition. A final debriefing questionnaire was administered following the completion of all data flight, eliciting subjective evaluation of the two coding conditions, the symbology,[1] the MFK logic, and the overall simulation quality.

Each of these three questionnaires is included in this Appendix with a tally of all of the pilots' responses. Nonparametric Kolmogorov-Smirnov tests of significance (Reference 10), were conducted on this data. The results are reported where the probability associated with the observed value of the maximum deviation is smaller than p = .05. Also included on each questionnaire is a composite of both the comments pilots wrote in on their questionnaires and comments they made during the flights. Occasionally, editorial comments are necessary to clarify the comment or the context in which it was made. These editorial comments are contained within brackets.

---

[1]During testing and questionnaire administration, the symbology was referred to as threat symbology. After the study it was decided to change the terminology to combat situation symbology since friendly and unknown symbols were included.

I. SHAPE-CODED SESSION DEBRIEFING QUESTIONNAIRE

1. Did you frequently confuse _____ with _____ at the following orientations, 12, 3, 6, 9 o'clock? If so, check (√) it.

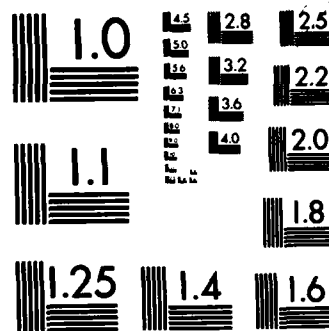| _____ With _____		Check (√)	
S̄	A͆S	_____	
S̄	(S)	1	
A͆S	(S)	6	
Ā	A͆	_____	12 O'CLOCK
Ā	(A)	1	
(A)	(A)	6	
⌐	∧	1	
⌐	∩	2	
∧	∩	14	
·]	>	2	
·]	⊙)	2	3 O'CLOCK
·>	⊙)	15	
⊔	∨	1	
⊔	⊍	2	6 O'CLOCK
∨	⊍	12	
[	<·	1	
[·	C·	2	9 O'CLOCK
<·	C·	14	

END
FILMED
DTIC

END
FILMED
DTIC

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

COMMENTS:

- ⊙ display at times was distorted to look like ⊙ , which was somewhat similar to ☜.

- No problem with orientation, only symbol sets for aircraft and AAA.

- Unknown symbol was easiest to detect in any orientation. The symbols for friendly and enemy were easily confused -- the display would cause friendly symbol to often look like enemy symbol.

- Once the ⊙ looked like [● then changed to ◀ and back to ⊙.

- In the black and white mode, the half-moon symbols and the spear-shaped symbols were difficult to distinguish.

- ∪ often was confused with ∨ -- visually ∪ was often thought of as unknown.

- Actually has nothing to do with the clock position, merely the identification when the symbology was shifting.

- The friendly versus enemy symbols are quite easily confused.

2. Did you have any difficulty in recognizing each of the following symbols at first glance? (For example, did you have to squint, move your head forward, or stare at it for several seconds before you could make it out?)

	Never	Very Little	Some	Quite a Bit	Always
S *(1)	12	3	1		
A *(2)	12	3	1		
⌐ *(3)	7	7	2		
∧ *	3	3	6	4	1
∩ (4)			8	6	4

*Some pilots did not respond.

(1) D=0.550, $p < 0.01$

(2) D=0.550, $p < 0.01$

(3) D=0.424, $p < 0.01$

(4) D=0.400, $p < 0.01$

COMMENTS:

- [See note 1] ◓ display at times was distorted to look like ◓, which was somewhat similar to ◓ .

- [◓ ◓ - Always] Again, same problem. In black and white, the spear-shaped symbols and the half-moon shapes were difficult to distinguish at first glance.

- White symbols near the top and bottom blended in with the other information presented and were difficult to pick out.

- Symbols are too small and have poor resolution.

- X hair on scope was the problem.

- When adjacent to other numerical information, especially at the limits of the scope, it required extra time.

3. How much do you feel the following symbols "looked like" what they were portraying?

	Not at All	Very Little	Somewhat	Quite a Bit	Completely
S(1)	1	1	3	4	9
A(2)	2	2	1	4	9
⌐	1	1	5	4	7
∧	2	2	5	6	3
⌒	3	7	4	3	1

(1) D=0.322, $p < 0.05$

(2) D=o.322, $p < 0.05$

COMMENTS:

-   [⌒ - Very Little] Confused with ∧ very much. Computer generated symbol is hard to differentiate.

-   A dot was too abstract to represent an aircraft for me, particularly a threat.

-   See note 1 [⌐⊙ display at times was distorted to look like ⊤⊙, which was somewhat similar to ⊤⊙ .

-   Differentiation is poor at best, even under optimum conditions -- unacceptable in daylight, under "G" loading, also sun glare.

-   As soon as you realize what they represented identification was O.K.

-   S to me means Search, therefore, nonthreat.

-   Without color, the shapes lose a lot of their impact value and distinguishability.

-   They don't have to look exactly like what they are portraying.

-   Airplanes should be shaped like "A's".

4.   How would you rate the adequacy of aircraft symbol orientation to denote aircraft heading (⬥ ⬥ ⬥ ⬥   )?(1)

	Very Poor	Poor	Adequate	Good	Excellent
*	___	1	1	7	8

(1) D=0.482, p < 0.01

*One respondent marked both "good" and "excellent". These responses were dropped.

COMMENTS:

- Symbols are only on cardinal heading.

- [Poor] Takes too long to figure out heading at a glance. Not too bad when you know in advance you're looking for aircraft heading towards a specific direction.

- [Good] Direction was indicated O.K.

5. During the experiment you were asked to perform three different types of threat tasks: Searching, Counting, and Comparing. Rate how easy it was for you to perform each of these types of tasks.

	Very Easy	Moderately Easy	No Opinion	Moderately Difficult	Very Difficult
Searching (In what quadrant is the S located?) (1)	3	10		4	1
Counting (Count the A.)	1	4	1	10	2
Comparing (Does quadrant 1 or 2 have more ● ?)	1	8		9	

(1) D=0.322, $p < 0.05$

COMMENTS:

- Without color, the search task becomes twice as difficult, which includes the requirement to count or compare.

- Difficulty was experienced when comparing friendly shapes with enemy shapes.

- Major problem encountered: ● sometimes misinterpreted for A.

- These tasks cannot be done at a glance. It takes some serious study of the scope.

- All threats had to be studied to first find the ones looking for, i.e., friendly, unknown, or enemy, then those threats had to be studied to find the type of threats questioned about. This as opposed to the color coded ones took more time.

- Color makes the difference.

- I really don't believe your questions are the correct ones for the data you are looking for. Yes, searching, counting, and comparing are performed--but there is very little "scope interpretation". With the system of asking the question in advance, you can key your mind on the symbology, quadrant, and direction of the different tasks. I think questions should be designed for scope interpretation-- what's really there, rather than searching for specific threats.

MISCELLANEOUS COMMENTS

- The quadrant dividing line caused me to confuse these two symbols in one case, ⚲ ⊙ .

- Every now and then the numerical information at the bottom of the display appeared very close to the threat information causing a little delayed reaction.

II.   COLOR- AND SHAPE-CODED SESSION DEBRIEFING QUESTIONNAIRE

1.   Did you frequently confuse ____ with ____ at the following orientations, 12, 3, 6, 9 o'clock? If so, check (√) it.

____ With ____		Check (√)	
ꞀＳ	ꜱ	1	
ꞀＳ	Ɡꜱ	1	
ꜱ	Ɡꜱ	2	
ꞀＡ	Ꜻ	1	12 O'CLOCK
ꞀＡ	ꞬꜲ	1	
Ꜻ	ꞬꜲ	1	
⊓	∧	1	
⊓	⌒	1	
∧	⌒	4	

ꓜ	＞	1	
ꓜ	ꓳ	1	3 O'CLOCK
＞	ꓳ	4	

⊔	∨	1	
⊔	ꞈ	1	6 O'CLOCK
∨	ꞈ	4	

ꞁ	＜	1	
[	ꓚ	1	9 O'CLOCK
＜	ꓚ	4	

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COMMENTS:

- Didn't look for $\wedge$ $\cap$ $\neg$ symbol. Just looked for color then looked to see if SAM, aircraft or AAA by symbol.

- With colors, I found the symbology to be fairly straight-forward.

- The color differences give immediate distinction between enemy, friendly, and unknowns. Only problem was within a color group remembering what symbol you're looking for.

- A little confusing between half-moon and spear shapes.

- Minor tendency to confuse symbols $\hat{A}$ for $\hat{\blacktriangle}$, that is A for "aircraft" versus anti-aircraft. One possible alternative is use $\hat{G}$ for anti-aircraft gun which is normally the method that intelligence will brief it.

- None.

- No problem.

- None, the color eliminated the problem.

- Symbols are confusing, i.e., $\hat{A}$ looks like an airplane. If color is used the $\wedge$ $\neg$ $\cap$ could be eliminated. Suggest:

	Red		Yellow		Green
Enemy AC	⋀	Unkn. AC	⋀	Friendly AC	⋀
Enemy SAM	S	Unkn. SAM	S	Friendly SAM	S
Enemy AAA	A	Unkn. AAA	A	Friendly [AAA]	A

The symbols could be larger and it might be good to make symbols different sizes, i.e., large symbols--higher threats.

2. Did you have any difficulty in recognizing each of the following symbols at first glance? (For example, did you have to squint, move your head forward, or stare at it for several seconds before you could make it out?)

	Never	Very Little	Some	Quite a Bit	Always
S *(1)	10	5	1		
A *(2)	10	5	1		
⌐ *(3)	10	5	2		
∧ *(4)	10	3	3		
∩ (5)	8	2	7	1	

*Some pilots did not respond.

(1) D=0.538, $p < 0.01$

(2) D=0.538, $p < 0.01$

(3) D=0.482, $p < 0.01$

(4) D=0.425, $p < 0.01$

(5) D=0.344, $p < 0.05$

COMMENTS:

- Friendly symbology could be de-emphasized a bit. In the heat of battle, I think you would only be concerned with the friendly's relative position.

- Not used to interpreting a ● as an AI airborne intercept threat. To me a dot is an unknown.

- Just don't like symbology--perhaps a circled Ⓔ would be better for the enemy.

- The S and A had to be read. I was unable to distinguish between them at glan like I was able to with the dot.

3. How much do you feel the following symbols "looked like" what they were portraying?

	Not at All	Very Little	Somewhat	Quite a Bit	Completely
S (1)		2		10	6
A	1	3	2	6	6
⊓	1	3	5	4	5
∧ (2)	1	1	2	7	7
∩	1	4	5	3	5

(1) $D=0.489$, $p < 0.01$

(2) $D=0.378$, $p < 0.01$

COMMENTS:

-   Can confuse A for A/C until used to symbology. Symbology OK once you are used to what they represent.

-   The bracket and half circle were no problem with color; however, I feel they may be a problem in black-white.

-   Same as above. [Just don't like the symbology -- perhaps a circled Ⓔ would be better for the enemy.]

-   [⊓ ∧ ∩ -- Completely "looked like" what they were portraying because of color coding.

-   The problem may be confusing the half-moon of the friendly with the spear-shape of the enemy.

4. How would you rate the adequacy of aircraft symbol orientation to denote aircraft heading (◆ ▶ ▽ ◀)?(1)

	Very Poor	Poor	Adequate	Good	Excellent
*	___	___	2	6	9

(1) D=0.482, $p < 0.01$

*One respondent marked midway between "poor" and "adequate." This response was dropped.

COMMENTS:

- You may consider making either the enemy aircraft symbol or the friendly aircraft symbol larger (if) when color is not used.

- Only cardinal headings are shown.

- Showing direction was good at a glance.

- Would be difficult at a glance under stress--especially low altitude.

- [Good] No problem with 90/270/360/180 headings. Other headings would be approximate.

5. During the experiment you were asked to perform three different types of threat tasks: Searching, Counting, and Comparing. Rate how easy it was for you to perform each of these types of tasks.

	Very Easy	Moderately Easy	No Opinion	Moderately Difficult	Very Difficult
Searching (In what quadrant is the Ⓢ located?) (1)	10	7		1	
Counting (Count the Ⓐ.)(2)	5	9		4	
Comparing (Does quadrant 1 or 2 have more ☜ ?)(3)	7	9		1	1

(1) $D=0.544$, $p < 0.01$

(2) $D=0.378$, $p < 0.01$

(3) $D=0.489$, $p < 0.01$

COMMENTS:

- The color contrast made it very simple to compare numbers of symbols in different quadrants.

- The pre-questioning keys your thinking--thus shortening the time. [Moderately Easy]

- Comparing was the hardest but none presented any real problem.

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6.   Do you feel the three colors chosen (red, yellow, and green)
were distinguishable enough? If no, why? (1)

<u>No</u>   <u>Yes</u>

__1__   __17__

(1) D=0.444, $\underline{p} < 0.01$

COMMENTS:

-    Color considerably enhances the ability of the pilot to
     distinguish between enemy and friendly. The only way to go
     with JTIDS. However, some minor adjustments to symbology
     should be considered.

-    Red and green were excellent. Yellow was a little difficult
     when it was close to the HUD [believe pilot meant digital
     readouts on HSF] scales around the edge.

-    Color worked fine!

-    [No] Do not think they would <u>work</u> in the daylight, in the
     sun glare. Also with the dark visor down it would all be
     different.

-    Suggest you drop ⋂ and ⋀ symbols when using color since
     they are redundant and use only basic symbols such as A
     S⬠.

7. Do you feel the saturation of each of the colors was correct? (For example, was the green, green enough?) If no, why?

	No	Yes
Green*(1)	___	_17_
Yellow*(1)	___	___
Red*(1)	___	_16_

*Some pilots did not respond.

(1) D=0.500, $p < 0.01$

COMMENTS:

- The symbol ☜ does not have the appearance of an aircraft. Whereas ⌂ and ⊙ remind me of swept wings of an aircraft.

- Again, you may want to de-emphasize the friendly symbols. The green may be too green.

- Much easier to distinguish threats with color. Easy to eliminate many symbols rapidly, thus focusing on specific tasked item.

- Same as above. [Do not think they would work in the daylight, in the sun glare. Also with the dark visor down it would all be different.]

- I don't see the need to have both indications of friendliness/unfriendliness. Color alone seems sufficient.

- Colors are very good and make the tasks easier; however, the symbols need a lot of work.

III. FINAL DEBRIEFING QUESTIONNAIRE

The purpose of this questionnaire is to gather information that will be helpful in the development of multifunction displays and controls for advanced fighter cockpit applications. The questionnaire is divided into four parts:

PART 1.   PERSONAL DATA - Information related to your background experience will be collected.

PART 2.   THREAT SYMBOLOGY - More information concerning the threat symbology presented on the Horizontal Situation Format will be collected. You will be asked to respond as to how the symbol coding (shape versus color and shape) and the number of symbols on the display affected your ability to identify threat symbols.

PART 3.   HUD SYMBOLOGY - Your opinion on the acceptability and useability of the symbology programmed on the simulator's HUD will be obtained. (Not included in this technical report.)

PART 4.   MULTIFUNCTION KEYBOARD (MFK) - Your thoughts regarding the use of a MFK which integrates many dedicated control functions onto a single panel made up of multifunction switches will be recorded. (Not included in this technical report.)

The extent to which this questionnaire can contribute to our data analysis will depend largely upon your candid opinion. Most of the questions can be answered with a check (√), but you are encouraged to make further comments. Please be as specific as possible.

PART 1

PERSONAL DATA

Name _____   Age Mean = 34 Years

Organization   9 pilots: 121 Tactical Fighter Wing, Rickenbacker
                          AFB
               9 pilots: 178 Tactical Fighter Group, Springfield
                          Municipal Airport

Present Assignment _____

Total Flying Time Mean = 2305 Hours

Total Jet Time Mean = 2064 Hours

Current Aircraft _____A-7D_____   Time in Type Mean = 493 Hours

Other Fighter Aircraft Flown   Time in Type

F-100	13 pilots: 12807 hrs
T-38	6 pilots: 1914 hrs
A-4	3 pilots: 1250 hrs
F-84	2 pilots: 1202 hrs
T-33	2 pilots: 293 hrs
T-37	2 pilots: 190 hrs
F-9	1 pilot: 170 hrs
F-86	1 pilot: 80 hrs

Total Years Rated Mean = 10 Years

What types of Head-Up displays have you flown?

(18) A-7 (Elliott)   ( ) In Combat
(1) F-111 (Norden)   ( ) In Combat
( ) F-15 (McDonnell-Douglas)   ( ) In Combat
(1) F-111 Simulator   ( ) In Combat
(1) A-10 Simulator   ( ) In Combat
(1) F-15 Simulator   ( ) In Combat

Civilian Job 10 Pilots: None
               1 Pilot : Corporate Pilot
               1 Pilot : Building Contractor
               1 Pilot : Northrop Marketer
               1 Pilot : Psychotherapist
               1 Pilot : Engineering Psychologist
               1 Pilot : Stock Broker - Account Executive
               1 Pilot : Corporate Manager
               1 Pilot : Engineer

PART 2
COMBAT SITUATION SYMBOLOGY

1. During the course of the experiment, you were asked questions about threat displays which contained either 10, 20, or 30 symbols. Sometimes the symbols were all white, sometimes the symbols were color-coded. How do you think the addition of color-coding affected the time it took for you to answer the question?

	Decreased It A Great Deal	Decreased It Some	Did Not Affect It	Increased It Some	Increased It A Great Deal
With 10 symbols(1)	10	7	1		
With 20 symbols(2)	15	3			
With 30 symbols(3)	16	2			

(1) D=0.544, $p < 0.01$

(2) D=0.633, $p < 0.01$

(3) D=0.689, $p < 0.01$

COMMENTS:

-   Color adds to the impact value and distinguishability of the symbology.

-   Felt very comfortable with color. Color reduced the time to respond considerably.

- The more symbols the more color coding helped.

- The colors make the tasks easier, especially if you must look quickly.

- Had to look at <u>every</u> symbol to determine what it was in black/white, but with color only looked at appropriate color.

- Removed deciphering problem between friendly/enemy aircraft.

2. How do you think the addition of color-coding affected the number of errors you made in recognizing the threats?

	Decreased It A Great Deal	Decreased It Some	Did Not Affect It	Increased It Some	Increased It A Great Deal
With 10 symbols(1)	7	8	3		
With 20 symbols(2)	12	6			
With 30 symbols(3)	14	4			

(1) D=0.433, $p < 0.01$

(2) D=0.600, $p < 0.01$

(3) D=0.600, $p < 0.01$

COMMENTS:

-   The more symbols displayed, the more the color helped. I really liked the color.

-   Color symbology eased assigned tasking, e.g., elimination of many threats that on black-white had to be integrated adding to length of time required to complete questions.

-   When there is a doubt between $\wedge$ and $\cap$ the color took the doubt out of it. Color is by far superior for threat recognition.

-   Need color for quick recognition or evaluation by a pilot in a tense, confused environment, such as combat.

- Errors could still be made because the symbols are slightly confusing.

- I may be wrong but I felt more comfortable with my answers using the color coding.

3. If this simulation had been an actual combat mission, how do you feel that the use of the threat display would have affected a successful completion of the mission?

	Hindered a Great Deal	Hindered Some	Would Not Have Affected It	Helped Some	Helped a Great Deal
With color coded symbols*(1)	___	___	___	3	14
With white symbols	1	3	3	10	1

*One pilot did not respond.

(1) D=0.578, $p < 0.01$

COMMENTS:

- Could not use the information on a low level ingress (below 150' AGL), oral information is more valuable when lookout doctrine is essential. There simply isn't enough time to interpret the symbology at low altitude, high airspeed ingress.

- Threat information is of extreme importance on a combat mission, in order for the pilot to alter his ingress/egress route, altitude, formation, target tactics, etc. The more accurate and up to date the threat information is, the better chance of mission success.

- With black/white there would have been more of a tendency to overreact to a friendly aircraft (i.e., breaking into it) closing on me.

- The color would be much more superior in obtaining the big picture of what is going on around you at a time this is very critical. This is especially true when you have many symbols on the tube.

- Using black and white with ten helped some. More than ten would hinder. I feel that 20 perhaps 30 items, with practice, on color presentation can be successfully achieved.

- Without color you could spend too much time in the cockpit whereas the color lets you get a feel of the situation at a glance.

- Without the color, it takes a longer time to evaluate what your screen is telling you. This means less time for looking outside, navigating, and in general, situation awareness.

- I probably would have begun ignoring the all white symbology simply because I would have been using valuable time searching through the clutter. Too much time was wasted telling "good" from "bad" with black/white. Recommend option to deselect "good guys" when using black/white.

- The threat display is very good and would allow you to avoid the threats.

MISCELLANEOUS COMMENTS

- Color is the better of the two, by far.

- Do we need direction on A or other than aircraft. Could eliminate some display on A or S.

NOTES TAKEN ON THE PILOTS' INFLIGHT COMMENTS

COMBAT SITUATION SYMBOLOGY

The majority of the pilots commented that they liked the color/shape coding condition better than the shape (monochrome) condition. With color, the pilots could identify threat states more easily.

Most of the pilots further commented that they had difficulty differentiating between enemy aircraft and friendly aircraft due to the symbol distortion when they shifted location. Some pilots suggested making the symbol more of a delta or adding longer wings.

This symbol confusion was true also for the ground threats. There were instances where Ⓐ and Ⓢ were confused with Ⓐ and Ⓢ.

A few pilots mentioned that the symbol for AAA, A, meant aircraft to them at times. In fact, some errors on threat tasks were due to the pilot looking at the AAA symbol rather than the airplane symbol.

The use of the hats on the color-coded ground threat symbols was thought to be unnecessary by a few pilots. One pilot felt that eliminating the hats would decrease recognition time.

The quadrant numbering system was confusing to several pilots. Two pilots commented that they would prefer the quadrants be numbered counter-clockwise starting in the upper-right quadrant and another two would prefer they be numbered clockwise starting in the upper-left quadrant. Another pilot mentioned he would prefer the quadrants numbered as follows: ▥

It was also noted that more of a delineation between the quadrant numbers and the readouts on the HSD would help.

OTHER COMMENTS:

- Threat symbol size too small.

- Enemy aircraft threats traveling 3 and 9 o'clocks are easier to identify than enemy aircraft threats traveling 12 and 6 o'clocks.

- Threat symbology used on A-7 RHAW scope may be better (U for Unknown aircraft symbol. etc.).

COCKPIT DISPLAYS

COMMENTS:

- Like having present position readout on MPD where it can be seen easily.
- In HSD, readout indicating number of minutes to the next waypoint, the readout should be in seconds rather than tenths of minutes when the aircraft is less than a minute away from the waypoint.

Many pilots commented that the slashes through the zeros made them difficult to differentiate from 6s and 8s.

SIMULATOR FACILITY

COMMENTS:

- Trouble seeing kneeboard.

- Stick feels heavy.

- RPM gauge does not have a fine scale. Makes it difficult
  to fine tune throttle.

- Stick seems too far forward.

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